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Data Base for Radioactive Waste Management

Impacts Analyses Methodology Report

Prepared by O. I. Oztunali, G. C. Ré, P. M. Moskowitz, E. D. Picazo, C. J. Pitt

Dames and Moore, Inc.

Prepared for
U.S. Nuclear Regulatory
Commission

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Prepared by
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1.0 INTRODUCTION

This report presents the methodologies utilized to calculate potential impacts resulting from the management of low level radioactive waste (LLW). The report considers three phases of waste management that may result in various types of impacts: (1) processing of the waste at the generation source or at a centralized location prior to disposal, (2) transportation of the waste from the generation source to the disposal location, and (3) disposal of the waste.

Potential impacts resulting from the management and disposal of LLW are expressed through "impact measures." Five quantifiable impact measures have been selected for treatment in this report: dose to the members of the public, occupational exposures, costs, energy use, and land use. Other impact measures may be quantified; however, the above five measures have been selected since they implicitly reflect many of the other impact measures.

The methodologies considered in the report include calculational procedures to determine:

- the occupational exposures and the exposures to the members of the public (individuals and population) resulting from the disposal of LLW;
- the occupational and the population exposures resulting from the processing of the waste at the generator location or at a centralized location (assumed to be at the disposal site), and the transportation of the waste from the waste generators to the disposal site;
- the costs and the energy use associated with processing, transportation, and disposal of LLW; and
- the land area committed to disposal of LLW.

These methodologies may be applied to a number of alternatives for waste form and packaging, disposal facility location, facility design and operation, and institutional controls to determine performance objectives and technical requirements for acceptable disposal of the wastes and to determine the environmental impacts of the selected alternatives.

This chapter provides an overview of the purpose and application of the impact analysis methodologies, presents the background rationale for the fundamental assumptions utilized in the development of the methodology and the data bases, and presents the approaches adopted to define the interfaces of the three phases associated with the management and disposal of LLW.

Chapter 2.0 discusses the waste-to-human pathways involved in the calculation of exposures to the members of the public. It includes a discussion of the basic rationale and background of the pathway analysis methodology, presents and analyzes the generic pathways considered in this report, and develops the equations applied in subsequent chapters.

Chapters 3.0, 4.0, and 5.0 address the three phases associated with the management and disposal of LLW, and discuss the disposal impact measures, transportation impact measures, and waste processing impact measures, respectively. Additional backup data and discussion regarding the pathway analyses are provided in three appendices addressing the pathway transfer factors, dose conversion factors, and reference disposal locations, respectively.

Finally, Chapter 6.0 contains a discussion of the computer codes written to perform the impacts analyses. Included in the discussion are the basic assumptions, general approach to the development of the codes, and a discussion of the analyses performed by each code. The listings of the codes and data bases utilized in the analyses are provided as Appendix D.

1.1 Purpose of the Study

The primary purpose of the impact analysis methodology is to provide a tool to enable determination of specific values of parameters that can be controlled and/or specified through technological or administrative action so as to assure the disposal of LLW in accordance with goals for management and disposal of LLW. These goals are the long-term and short-term protection of the human environment.

The long-term protection of the human environment may be achieved by reducing to acceptable levels: (1) radiological impacts to the members of the public, and (2) long-term social commitment. The level of radiological impacts may be quantified through calculating individual and population exposures resulting from handling and disposal of LLW. The level of long-term social commitment may be quantified through calculating the long-term costs for site control and surveillance, as well as the amount of land committed to LLW disposal. Other impact measures address the short-term protection of the human environment.

The secondary purpose of the impact analysis methodology is to enable the calculation of the selected impact measures associated with a given disposal facility containing several waste streams with different characteristics.

1.2 Background

Recent events have shown that the resolution of uncertainties in the management and disposal of LLW is of national importance,(1-6) and that the development of LLW regulations and the necessary supporting documents continues to be an important issue. Guidance is needed not only to address specific day-to-day disposal problems at the existing operating sites, but also to address the stabilization and final closure of the sites that are no longer operational, and to provide better guidance to applicants seeking to establish new LLW disposal facilities. One of the tools needed to provide this guidance is a workable methodology for determining what disposal requirements are applicable for a given type of waste -- i.e., a waste classification methodology.

The primary reason for the development of a waste classification methodology is the need to assure that uniform and environmentally acceptable practices are adopted throughout an extremely diverse industry that generates LLW with varying physical, chemical and radiological characteristics. Definition of specific waste categories, to allow for a commonly understood basis for managing LLW, would resolve many of the issues facing the industries that produce and dispose of LLW.

Several waste classification systems have been proposed and are summarized in reference 7. Based on a review of these proposed systems, reference 7 concludes that a viable waste classification system should be based on the ultimate disposition of the waste material. It further outlines three potential methods for disposition of the wastes, namely, (1) discharge directly to the biosphere for innocuously low-level wastes, (2) active confinement for low-level waste, and (3) isolation for high-level waste. This classification system is illustrated in Figure 1.1.

Reference 7 also concludes that the method governing the disposition of the waste should be based primarily on its hazard potential and expressed in terms of radioactivity per unit volume or mass at the time of disposal. The reference goes on to note that the interfaces of the three disposal categories are yet to be established, that the issue of whether or not specific activity limitations should be established for individual isotopes or groups of isotopes has not been resolved, and that a total activity inventory limit may have to be established for each disposal facility in order that the radiological impacts remain below the established guidelines.

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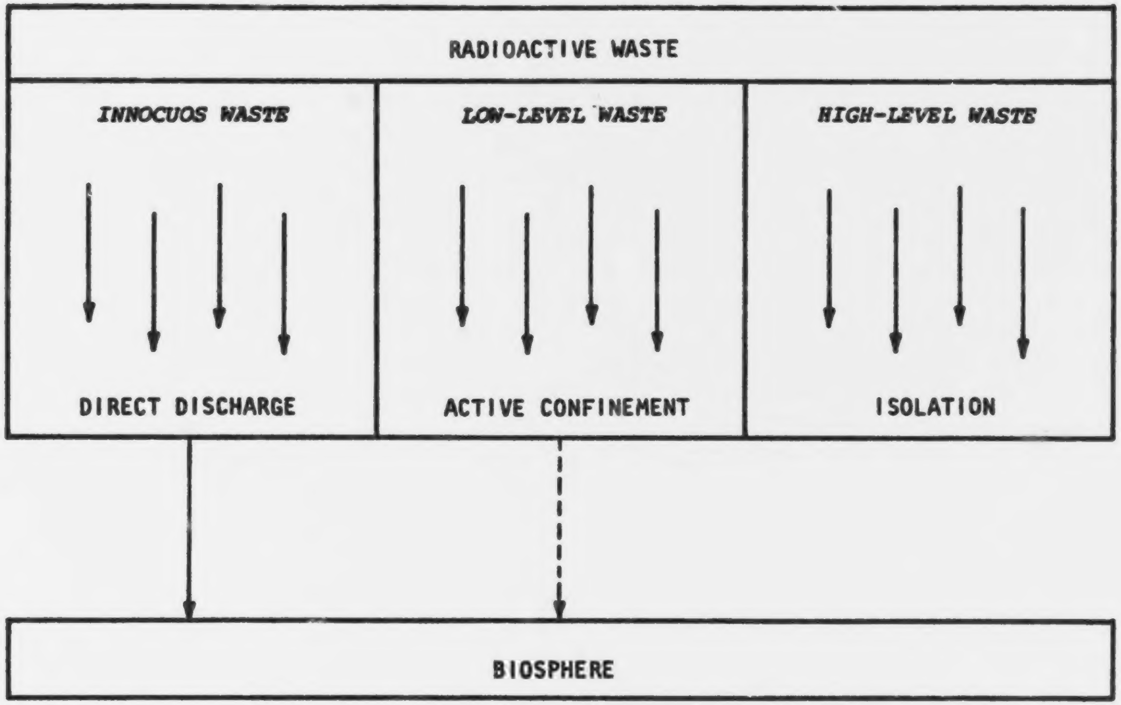
RADIOACTIVE WASTE
INNOCUOS WASTE
LOW-LEVEL WASTE
HIGH-LEVEL WASTE
DIRECT DISCHARGE
ACTIVE CONFINEMENT
ISOLATION
BIOSPHERE

SCHEMATIC OF RADIOACTIVE WASTE CLASSIFICATION SYSTEM

DAMES & MOORE

FIGURE 1.1

A subsequent attempt to quantify the interfaces of the above three disposal categories is presented in reference 8. This report details a three-category waste classification system determined by two reference disposal methods and the corresponding acceptance tests. The reference disposal methods which determine the interfaces of the three classes are based on the shallow land burial and sanitary landfill disposal concepts. A following report(9) expands on the "work in progress" presented in reference 8, and outlines a classification system composed of five classes which are delineated by radioactive concentration guides.

The impact analysis methodology presented in this report is one of the tools which may be used to develop a waste classification system and determine the interfaces of the eventual disposal categories. This report devotes considerable attention to the variable conditions of LLW and potentially viable different disposal technologies.

1.3 General Approach

The most important rationale governing the selection of the methodologies and the calculational procedures used in this report is the generic nature of the analysis. The methodologies are focused toward helping to establish generic criteria for LLW management and disposal rather than calculating impacts at a particular disposal facility.

This is especially significant in view of the level of information available for a generic analysis as opposed to the level of data which will be available for a specific disposal facility site. Increased complexity and sophistication of a calculational procedure cannot compensate for a lack of data. Moreover, increased complexity and sophistication cannot compensate for the fact that all calculational procedures are based on an idealized picture of the system; this is an integral aspect of all predictive tools which are an essential part of many of the decision making processes. Therefore, the sophistication and level of complexity of the calculational procedures must be consistent with the level of data that can be inferred and/or generalized for a generic system.

There are many possible methods or combination of methods which may be used to calculate the potential impacts of LLW disposal; these range from very simple to very complex techniques.(9-12) Extremely complex calculations may be called for when analyzing a specific site where a significant quantity of site-specific information is available and where specific facility designs for the waste disposal may be considered. However, for generic types of analyses to support an environmental impact statement and a rulemaking effort, where one is interested in the relative costs and impacts of alternative actions, simpler calculational schemes appear to be more appropriate. This concept of increasing the complexity of calculational schemes with the increasing amount and specificity of the available data is consistent with the concept of tiering as set out by regulations promulgated by the Council on Environmental Quality (CEQ).(13)

A second governing rationale for the selection of the methodologies and the calculational procedures in this report is the necessity to consider viable alternatives during three different waste management phases (waste processing, transportation, and disposal) and the requirement that the interfaces of these three phases be properly coordinated. For example, waste processing techniques which reduce waste volumes would also likely result in an overall increase in the radioactive contents of the waste packages. This may result in additional transportation and disposal requirements that should be accurately represented. Furthermore, specific transportation scenarios (e.g., all truck shipments with Type B overpacks) could result in different requirements for waste handlers at the disposal site. This complicating factor indicates that the selected procedures should be as simple as feasible for proper coordination.

Another example of a factor complicating an accurate definition of the interfaces is the possibility that the waste processing may occur at the waste generator's site or at a centralized regional location. This aspect has to be included in the calculation of the impact measures, specifically the transportation impacts.

A third rationale for the selection of the methodologies is the need to have a flexible methodology that can be updated in a straightforward manner as additional information is obtained. Any methodology that cannot accommodate timely changes is bound to become obsolete in a short time. The methodologies selected provide for continuous updating of the calculational techniques and the data base used for the analyses.

The general criteria used in the development of the impact analyses methodology (IAM) are as follows:

- The IAM should be constructed in terms of measurable properties of the waste and the disposal environment;
- The IAM should be able to treat extreme values of these measureable properties;
- The IAM should be able to consider diverse impact measures associated with the disposal of LLW;
- The IAM should be capable of rapid calculation of these impact measures;
- The IAM should be able to assess the comparative importance of the measurable parameters in affecting the impact measures; and finally,
- The IAM should allow the incorporation of more complex and sophisticated calculational procedures, if necessary.

1.4 Impact Measures

Five basic impact measures are quantified in this report to determine a preferred alternative or option associated with the management and disposal of LLW. Two of these measures - individual and population exposures associated with the handling and disposal of the waste - are representative of the level of long-term protection of the human environment from radiological impacts. The other measures - costs, energy use, and committed land area associated with the disposal of waste - are representative of the level of long-term protection of the human environment from socioeconomic impacts. Other potential impact measures, such as man-hours and material requirements (e.g., clay, gravel, concrete), are implicitly included in the above five impact measures. In view of past disposal history and practices,(1) impact measures related to long-term protection of the human environment are stressed in this report.

The methodologies selected for determination of individual and population exposures resulting from the disposal of waste, which are discussed in Chapter 3.0, are primarily geared towards the generic nature of the analysis. Accordingly, determination of the relative effects of various barriers between the waste and the human environment - waste form and packaging, site selection, site design and operation, and institutional controls - occupy a prominent place in the formulation of the calculational procedures for the disposal impacts. Potential occupational exposures from waste disposal are calculated based upon assumptions regarding the interface between waste transportation and waste disposal. In comparison, calculation of other impact measures - cost, energy use, and land use - is relatively straight-forward based on the information and assumptions presented in the other volumes of this data base.(1,14)

The impact measures associated with waste processing and transportation -- i.e., occupational and population exposures, costs, and energy use -- are all representative of the level of short-term protection of the human environment afforded by the alternatives considered; it is assumed that no land is permanently committed during waste processing and transportation activities. Again, impact measures other than these four are implicitly included in the selected set of measures.

The transportation impact measures are straightforward functions of the packaging and shipping mode assumptions detailed in Chapter 4.0, and the population exposure calculational procedures given in documents such as references 15 and 16. Impact measures associated with waste processing, presented in Chapter 5.0, are calculated based on the assumptions presented in reference 14 and the transfer factors developed in Appendix A.

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2.0 PATHWAY ANALYSES

After the waste has been disposed of through an acceptable method, control mechanisms such as waste form (processing), site selection, site design and operation, site closure, and institutional controls begin to function. It is these control mechanisms that constitute "barriers" which confine and control to acceptable levels the interaction of the waste with the environment.

This chapter details the mechanisms through which the waste may interact with the environment after disposal, and quantifies these interaction mechanisms in terms of applicable control mechanisms and the characteristics of the disposal system. The characteristics of the disposal system include those associated with waste form and packaging,(1) facility design and operation,(2) and administrative requirements.

A brief introduction to the basic rationale and the development of the pathway analysis methodology is presented in Section 2.1, while the alternative release/transport/pathway routes through which the waste may interact with the environment (scenarios) are discussed in Section 2.2. The calculational procedures for determining the potential exposures resulting from selected release/transport/pathway scenarios are presented in Section 2.3, while the release/transport mechanisms are quantified in Section 2.4. Additional information regarding the radioactivity transfer factors utilized in Section 2.4 is provided in Appendix A.

2.1 Introduction

There are many diverse mechanisms through which radionuclides contained in LLW may be potentially released (i.e., mobilized from the waste and become accessible to a transport agent such as wind or water), transported through the environment (i.e., moved from one location to another through the atmosphere or soil by a transport agent), and thereby become accessible to humans through various pathways. Human access to the radioactivity may result either through direct human contact with contaminated material (e.g., inhalation of air, ingestion of water, or direct exposure to radiation) or indirectly through contaminated biota (through a multitude of pathways involving vegetation and animals) which have come into contact with contaminated material.

Each of these radionuclide release/transport/pathway combinations (scenarios) represents a complex series of interactions which are affected by a wide range of parameters such as waste properties, disposal site properties, and operational procedures. These diverse release/transport/pathway scenarios must be unified so as to achieve a simple, accurate, and readily usable methodology for pathway analysis. The development of the methodology employed in this report for pathway analysis is based on the following procedure:

- Define and analyze, as completely as is practically possible, all the potential release/transport/pathway scenarios that may lead to radiation exposures to either individuals or populations, and select the significant scenarios for further analysis.

- Simplify the structure of the selected release/transport/pathway scenarios by separating the radiation release and transport mechanisms from the pathway mechanisms. In other words, separate the calculational procedures used to model release of radionuclides from the waste and movement of radionuclides through the environment from those calculational procedures used to model the resulting dose to humans.

- Determine applicable radionuclide-specific dose conversion factors for various human organs from human exposure to contaminated material for all release/transport/pathway scenarios.

These dose conversion factors, henceforth called the pathway dose conversion factors (PDCF's) to distinguish them from the conventional use of the term "dose conversion factor" (which are referred to as fundamental dose conversion factors in this report), are determined for an entire pathway to permit rapid determination of dose equivalent rates to human organs.

- Model the radioactivity release and transport mechanisms between the disposed wastes and the locations where the radionuclides may be contacted by humans (the "biota access locations"). Then identify the control mechanisms and barriers that may be technologically or administratively implemented that affect these release and transport mechanisms.

- Utilizing the information presented in references 1, 2 and Appendix C, determine the various options available for these control mechanisms in terms of waste form and packaging, facility site selection, facility design and operation, and institutional requirements.

- Finally, determine the potential radiological impacts from the disposed LLW for various alternative options.

The methodology considers only one radionuclide at a time. Total impacts resulting from the movement of radionculides from the waste and through the environment are obtained by summing over all of the radionuclides assumed to be present in the LLW. Several radionuclides considered,(1) however, result in decay chains. These decay chains are implicitly included by incorporating the effects of the daughters through the dose conversion factors for the parent radionuclide or by decaying the appropriate fraction of the parent radionuclide and adding it to the daughter radionuclide inventory as in the case of the decay of Pu-241 to Am-241. However, more detailed consideration of radionuclide chains would be appropriate during an analysis for a specific disposal facility location.

2.2 Release/Transport/Pathway Scenarios

In accordance with the first two steps outlined above, the definition and simplification of the potential release/transport/pathway (RTP) scenarios that are quantifiable and can lead to significant radiation exposures to humans are discussed in this section. The approach to the definition of the RTP scenarios is presented in Section 2.2.1, applicable release/transport scenarios are discussed in Section 2.2.2, control mechanisms that may be applied to these scenarios are discussed in Section 2.2.3, and the RTP scenarios not included in detail in this report are considered in Section 2.2.4.

2.2.1 Approach

The conventional approach to quantifying the routes and pathways between radioactive materials and humans, and thereby determining the resulting radiological impacts, is widely known and can be found in the literature.(3-5) A representative diagram is given in simplified form in Figure 2.1.

As shown in this figure and beginning with the disposed waste, the transfer of radionuclides (and/or direct ionizing radiation) is traced along numerous transport paths as the contamination is transferred between adjoining compartments and is eventually taken up by humans. The boxes represent the contaminated media and the arrows indicate that contaminant transfer can occur between adjacent compartments via the stated radionuclide-mobilizing mechanism.

This classical pathway methodology is very useful in determining specific impacts associated with a particular disposal facility, but is unfortunately a bit awkward for use in determining generic regulatory requirements. This results from the fact that most of the arrows between the boxes represent environmental parameters that are site specific, and depend on the location of the disposal facility.

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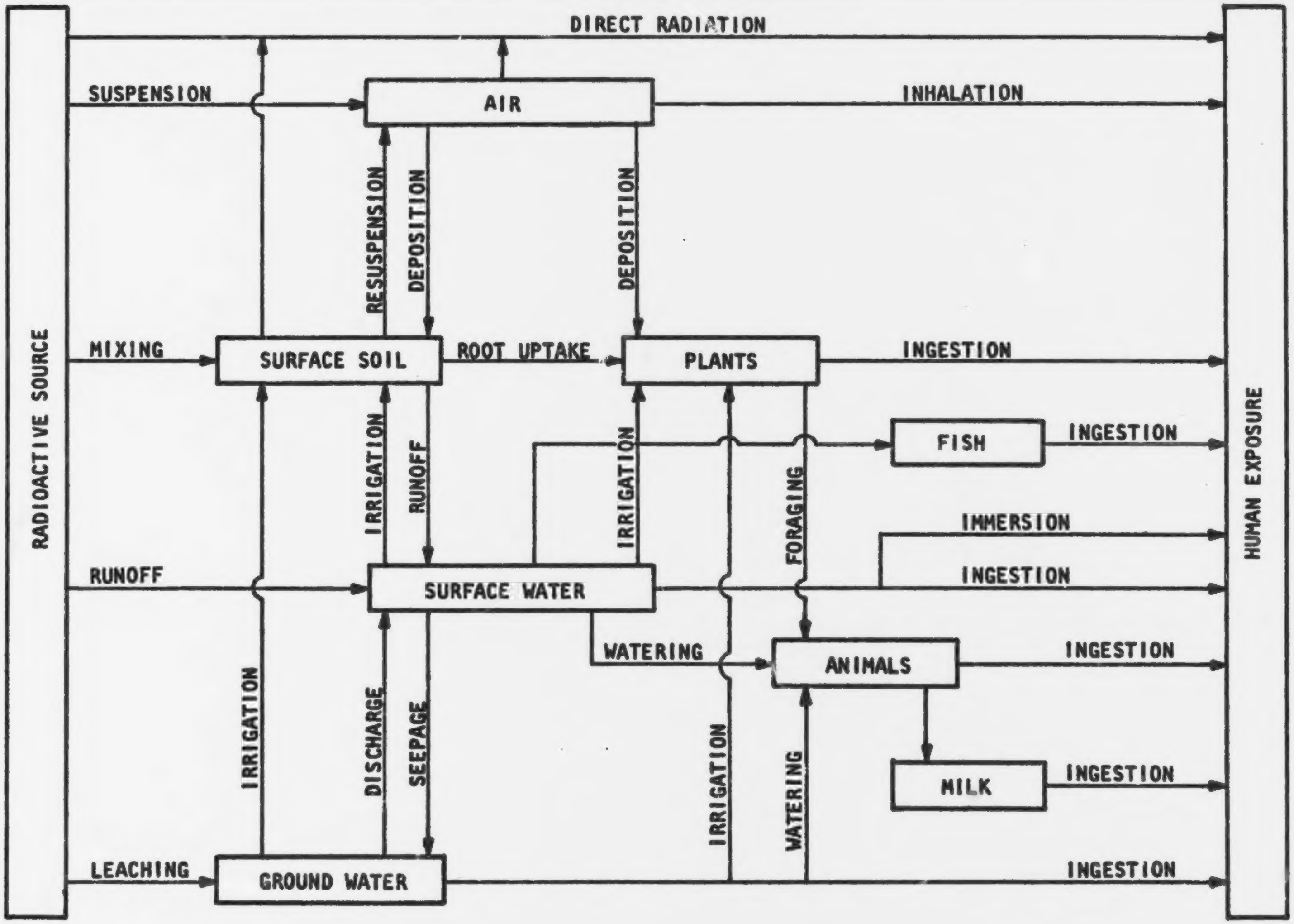
2-5

FIGURE 2.1

DAMES & MOORE


RADIOACTIVE SOURCE
DIRECT RADIATION
SUSPENSION
AIR
INHALATION
RESUSPENSION
DEPOSITION
DEPOSITION
MIXING
SURFACE SOIL
ROOT UPTAKE
PLANTS
INGESTION
FISH
INGESTION
IRRIGATION
RUNOFF
IRRIGATION
FORAGING
IMMERSION
RUNOFF
SURFACE WATER
INGESTION
WATERING
ANIMALS
INGESTION
IRRIGATION
DISCHARGE
SEEPAGE
IRRIGATION
WATERING
MILK
INGESTION
LEACHING
GROUND WATER
INGESTION
HUMAN EXPOSURE

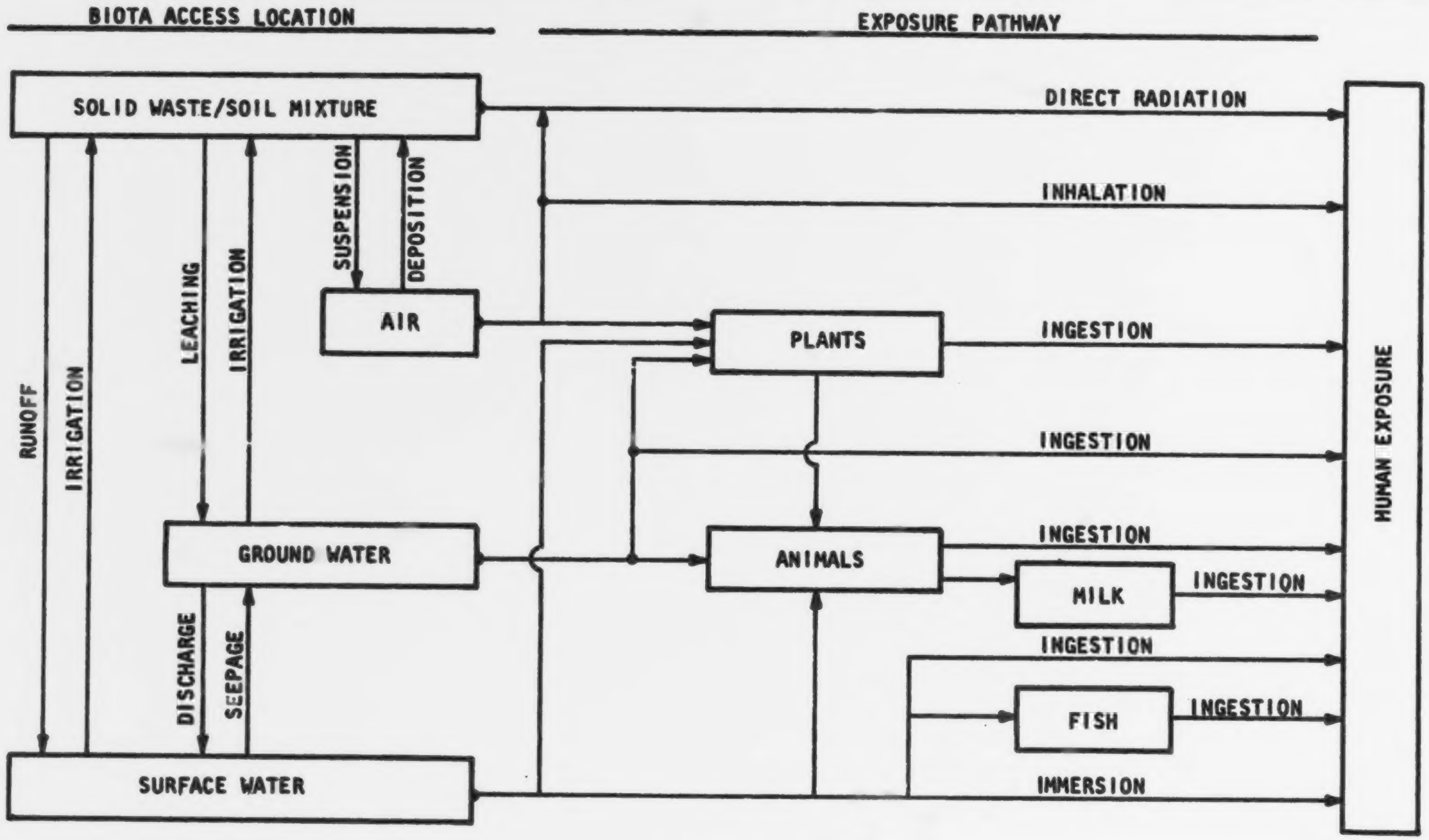
CLASSICAL PATHWAY DIAGRAM

Moreover, the diagram does not permit rapid identification and analysis of alternative control mechanisms, which may be used to reduce or eliminate the potential radiological impacts.

To aid in analyzing alternative overall performance objectives and technical criteria, a more practical calculational procedure is needed which separates those parameters that can be controlled (through technological and/or administrative requirements) with a high degree of confidence from those that cannot be controlled with the same degree of confidence. For example, waste form and packaging are parameters that may be potentially controlled with a higher degree of confidence than such parameters as the irrigation rate of crops, which must be assumed to be uncontrollable. A pathway diagram that has been rearranged in order to satisfy these conditions is presented in Figure 2.2.

As can be seen in this figure, most of the site specific pathway compartments and parameters have been separated from the rest of the diagram at what are termed the biota access locations. Most of the parameters which can be controlled (which are the solid waste/soil mixture box and the connections of this box with the other biota access locations) have been separated from the rest of the diagram. The significance of this separation is that performance objectives, technical requirements, and administrative regulations which would be formulated to reduce the radiological impact of LLW disposal would be aimed at the controllable parameters.

After the contamination reaches a biota access location, it becomes available for immediate or eventual uptake by humans. Comparatively little control (mostly through site selection) can be implemented over the segments of the pathways beyond these biota access locations (e.g., selection of a desert location may minimize ingestion pathways). Because of this comparative lack of control, movement of radionuclides through the pathways beyond the biota access locations


BIOTA ACCESS LOCATION
EXPOSURE PATHWAY
SOLID WASTE/SOIL MIXTURE
RUNOFF
IRRIGATION
LEACHING
IRRIGATION
SUSPENSION
DEPOSITION
AIR
GROUND WATER
DISCHARGE
SEEPAGE
SURFACE WATER
PLANTS
ANIMALS
MILK
FISH
DIRECT RADIATION
INHALATION
INGESTION
INGESTION
INGESTION
INGESTION
INGESTION
INGESTION
IMMERSION
HUMAN EXPOSURE

MODIFIED PATHWAY DIAGRAM

FIGURE 2.2

DAMES & MOORE

and the resulting human exposures may be expressed through radionuclide specific pathway dose conversion factors (PDCF's) that are independent of the original means of contamination. Based on an appropriate reference concentration at the biota access location (e.g., 1 Curie/m^3 of contaminated media), the dose to humans may be calculated for each pathway from the biota access location to the point of eventual human exposure. In other words, once the radionuclide concentrations at the biota access locations are known, potential human exposures may be determined by multiplying the actual access location concentration C_a (in units of Ci/m^3) by the PDCF (in units of millirem per Ci/m^3):

$$H = PDCF \times C_a \tag{2-1}$$

where H is the human dose in millirem (see Section 2.3). As an example of the development and use of a particular PDCF, consider the impacts that could result to a human from the presence of a concentration of radioactivity in off-site air. Potential exposures could result from the following uptake pathways:

- Inhalation of the contaminated air,
- Direct ionizing radiation[*] exposure from standing in the contaminated air;
- Consumption of leafy vegetables dusted with radionuclides settled out of the air;
- Direct ionizing radiation[*] exposure from contaminated dust deposited on the ground;

---

[*] Direct ionizing radiation referred to in this report includes alpha, beta, and gamma radiations. Alpha and beta radiations have very short ranges and usually only gamma radiations are considered in the impact calculations. However, beta radiation has been included in this work in the fundamental dose conversion factors for the above exposure scenarios (see Appendix B).

- Inhalation of contaminated dust which has been resuspended from the ground surface;
- Consumption of vegetables containing radionuclides transferred into the plant through root pathways; and
- Consumption of food containing radionuclides transferred to the food through various pathways such as plant-animal-meat or plant-animal-milk.

At a specific site, the dose resulting from these uptake pathways would be determined through the use of (1) transfer factors such as air-to-leaf and soil-to-air transfer factors, and (2) fundamental dose conversion factors (DCF) such as the inhalation DCF (50-year committed dose per pCi inhaled), ingestion DCF (50-year committed dose per pCi ingested), and direct radiation DCF (annual dose per unit concentration in the contaminated medium). The transfer factors and the actual potential impacts would be specific to particular environmental conditions (e.g., humidity, types of food grown, etc.) and specific human actions at the location where the airborne contamination occurred.

However, for generic analyses, reasonable yet conservative assumptions may be made regarding environmental characteristics and human actions. Based upon these assumptions, a unit concentration of a radionuclide in air (e.g., 1 Ci/m^3), and the fundamental dose conversion factors (i.e., ingestion, inhalation, and external exposure), the potential individual organ doses that could occur as a result of each uptake pathway could be calculated. Then the doses from each uptake pathway may be summed to form, for each individual organ, a single pathway dose conversion factor that represents the total potential dose received from all uptake pathways. The end result is the ability to quickly determine on a generic basis (e.g., by consulting a table and multiplying), the total potential organ doses received by a human from any concentration of radionuclides in air.

This approach introduces a conservatism in the calculation of doses since not all of the uptake pathways may be applicable for every release pathway and environmental setting. The generic nature of the analysis, however, precludes a detailed consideration of site specific pathway factors.

2.2.2 Release Scenarios

There are three fundamental transport agents which can mobilize radioactivity from disposed waste:

- Direct Contact - The waste may be directly accessed by humans through ionizing radiation exposures or through human activities which contact the waste/soil mixture.
- Air - Air can mobilize radioactivity from the waste when the waste is directly exposed to the atmosphere.
- Water - Ground water and surface water can act as transport agents to mobilize radioactivity from the waste.

Moreover, there are two comparatively distinct time periods of the site lifespan during which releases from LLW can reach a biota access location: the operational period and the post-operational period. The post-operational period may be further divided into the closure and observation period, the active institutional control period, and the passive institutional control period.

Operational Period - The operational period includes the time during which the waste disposal operations takes place. During this period, the principal mechanism at a disposal facility that can result in significant transport of radioactivity to a biota access location is an operational accident. In this case, wind is the primary transport agent, the biota access location becomes off-site air, and the exposure period is acute - i.e., a discrete event occurring over a short time span.

During this period, the site operator is responsible for the control and maintenance of the site. Potential impacts from operational accidents are important but not directly related to the long-term performance of a near-surface disposal facility. Operational accidents are important insofar as potential operational releases may be precluded or minimized by improvements in waste form and packaging or site operational procedures. Occupational exposures and potential off-site exposures due to surface run-off from contaminated on-site soil may occur; however, they are not quantified in this report. Such potential short-term exposures would be addressed as part of licensing specific disposal facilities. Routine occupational exposures during the operational period are considered in Chapter 3.0. Groundwater migration is not calculated during this period for calculational convenience, and because of the short time span and operational measures that could be taken to minimize the potential for migration.

During the operational period, other short-term exposures would also result at locations other than the disposal facility site. Exposures to populations could result from airborne releases of radioactivity during waste processing activities -- especially if such processing activities involve incineration of combustible waste streams. Such processing activities would be performed by the waste generator or at centralized processing centers. Population exposures would also occur during waste transportation to the disposal facility. Occupational exposures would result to waste handlers while generating and processing waste streams, as well as to personnel transporting the waste to the disposal facility.

Closure and Observation Period - This period lasts from the end of disposal operations at the facility to the time that the title for the facility is transferred to the site owner. The period begins during the time that disposal facility is closed and lasts through any period of observation carried out by the site operator to assure that the disposal facility is in a stable condition prior to transfer to the site owner. During this period, the facility operator is responsible for the control and maintenance of the site. The groundwater scenarios are initiated during this period. Groundwater may transport radioactivity to locations where the radioactivity may be accessed by humans. Possible access locations would include either a well drilled into the contaminated aquifer or open water (e.g., a stream) into which the contaminated aquifer has discharged. For both of these cases the exposure periods are chronic (i.e., continuous events).

Active Institutional Control Period - This period lasts from the transfer of the title of the site by the site operator to the site owner until a point in time at which a breakdown in active institutional controls is assumed to occur. During this period, the waste is not exposed to the atmosphere. The waste may, however, interact with humans through direct radiation attenuated through the disposal cell cover. Thus, the waste itself is an access location. The other principal agent that can transport radioactivity from the waste during this period is groundwater, which continues during this period.

Prior to the transfer of the title to the site owner, the site will be closed by the site operator. A desirable goal during the closure activities is that the site will have been stabilized so that there is essentially no need for active ongoing maintenance by the site owner. During the active institutional control period, the site owner is responsible for the care and maintenance of the site. Access to the site is restricted (e.g., fenced) and/or controlled by means of some manner of licensed surface use. The direct radiation exposure scenario, in comparison with other scenarios, is likely not to be significant since the radiation must pass through the intact trench cover. The groundwater scenarios are assumed to continue during this period.

Passive Institutional Control Period - During the passive institutional control period (after active institutional controls are assumed to have broken down), the waste may be exposed to the atmosphere through erosion or human activities. During this period, the waste/soil mixture may, potentially, be directly accessed by humans. For example, a house could be inadvertently constructed on the waste disposal facilty and after the house is constructed a person or small group of persons could live in the house and possibly consume garden vegetables inadvertantly grown in the waste/soil mixture. These two potential inadvertent intruder scenarios are referenced several times in this report and are referred to as the intruder-construction scenario and the intruder-agriculture scenario. In addition, wind and water may act as transport agents that may lead to dispersion of radionuclides and off-site contamination of air and open water, respectively. In the case of direct human contact with the waste/soil mixture, the exposure period is acute for the inadvertant intruder-construction scenario, and chronic for the inadvertant intruder-agriculture scenario. For scenarios involving the wind and surface water transport agents, the exposure periods are chronic. The groundwater scenario continues during the passive institutional control period.

During the active institutional control period, it may be assumed that active controls exercised by the site owner on the closed disposal facility will gradually lessen. The period of time between the site inspection and routine monitoring of the site will lengthen. Eventually a passive institutional control period may be assumed during which the control of the site is principally expressed through site ownership and control of land use. During this period, there may be occasions in which inappropriate use of the facility by people occurs. As extreme examples of inapropriate use, a house may be constructed on the disposal facility and persons may live in the house. It is likely, however, that the passive institutional controls would preclude continuation of inappropriate site use for long time periods.

The seven pathways that have been discussed above (one for the operational period, two for the closure and observation period, one for the active institutional control period, and three for the passive institutional control period) are summarized in Table 2-1. A brief discussion of the release/transport/pathway scenarios not considered quantitatively in this report is given in Section 2.2.4.

For calculational purposes, it is convenient to reorganize these seven pathways. This modification involves breaking up the passive institutional control period on-site soil exposure pathway into two exposure scenarios (inadvertant intruder-construction and inadvertant intruder-agriculture), and eliminating the active institutional control period on-site soil exposure scenario since it involves potential radiation exposure attenuated through an intact disposal cell cover. These exposures are not expected to be significant as long as the disposal cell cover is intact. Direct radiation exposures to a potential intruder are considered as part of the above inadvertant intruder scenarios. The resultant seven pathways are illustrated in Figure 2.3.

All of these pathways involve PDCF's which are composed of more than one uptake mechanism, i.e., there are secondary biota access locations such as off-site air containing wind suspended radionuclides that were deposited after wind transport from the waste. Additional information on secondary biota access locations is provided in Section 2.3.2.

2.2.3 Control Mechanisms

The release and transport of radioactivity from the disposed LLW are significantly affected by the properties and characteristics of the waste form and packaging, site design and location, disposal practices, etc. Most, if not all, of these items are controllable to some degree. Specific controls of these items can be made mandatory through administrative regulation; hence these may be termed regulatable items or control mechanisms.

In order to permit the specification of controls and the quantitative assessment of their effects, these control mechanisms should be

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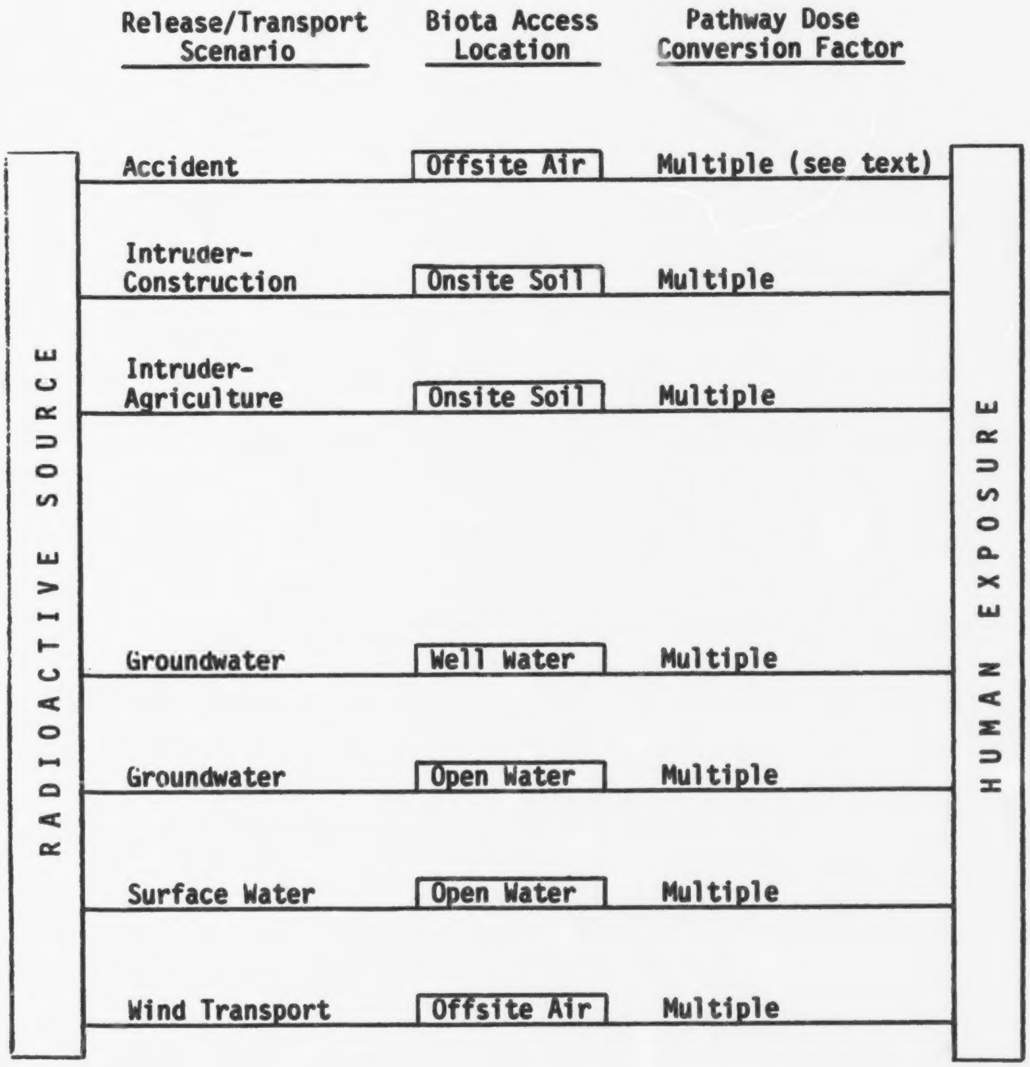
TABLE 2-1

Major Pathways for LLW Disposal Facility

Period Pathway Initiated	Transport Agent	Biota Access Location	Exposure Period
Operational Period	Wind	Off-site Air	Acute
Closure and Observation Period	Groundwater	Well Water	Chronic
	Groundwater	Open Water	Chronic
Active Institutional Control Period	Direct Radiation	On-site Soil	Chronic
Passive Institutional Control Period	Direct Access	On-site Soil	Chronic or Acute
	Wind	Off-site Air	Chronic
	Surface Water	Open Water	Chronic

FIGURE 2.3 : Simplified Pathway Diagram



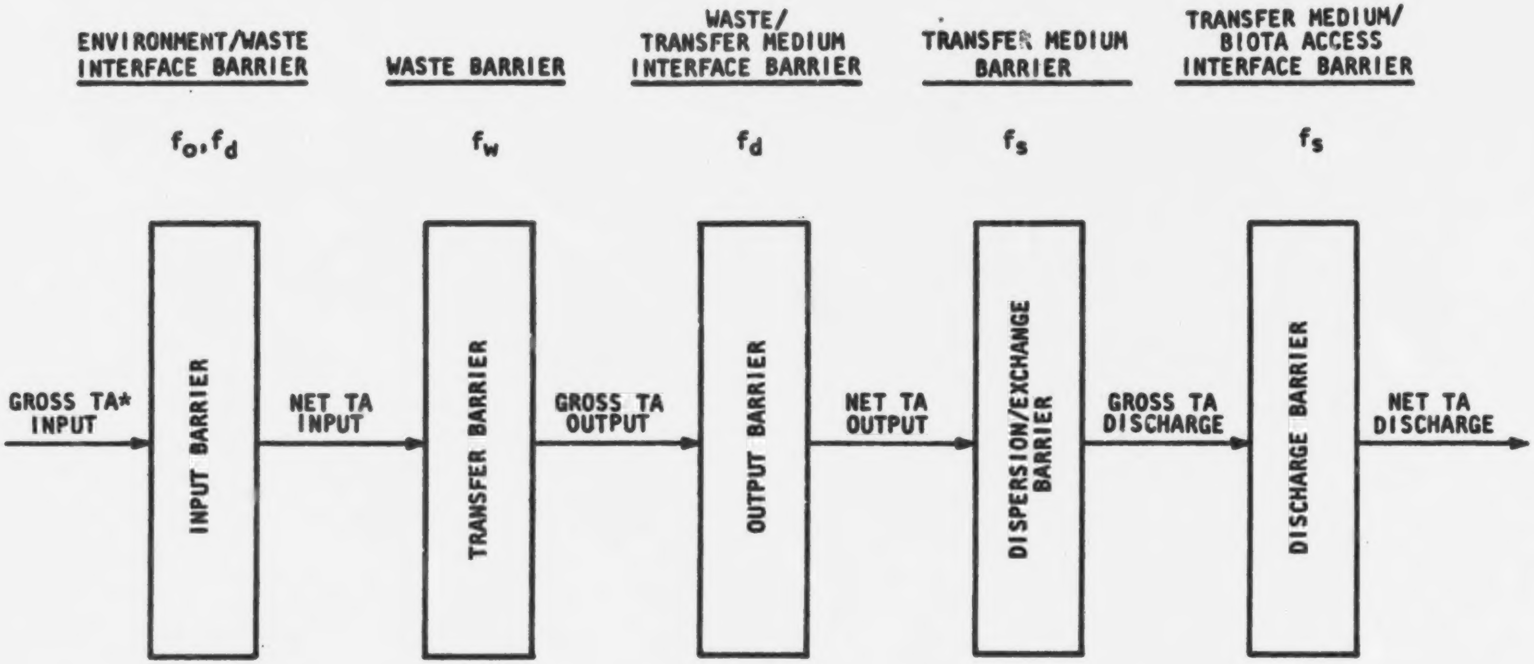
Release/Transport Scenario	Biota Access Location	Pathway Dose Conversion Factor
Accident	Offsite Air	Multiple (see text)
Intruder-Construction	Onsite Soil	Multiple
Intruder-Agriculture	Onsite Soil	Multiple
Groundwater	Well Water	Multiple
Groundwater	Open Water	Multiple
Surface Water	Open Water	Multiple
Wind Transport	Offsite Air	Multiple

identified unambiguously. To accomplish this, each release/transport mechanism may be broken down into its component parts. This breakdown is illustrated in Figure 2.4 and in the following example regarding potential groundwater migration.

Figure 2.4 schematically traces the progress of a given transport agent (e.g., water) from initial input to the waste to eventual output at the biota access location. For example, consider the action of rain water on a shallow land burial facility. Rain water (the initial form of the transport agent) may seep down into the waste, contact and leach radioactivity from the waste (thereby becoming leachate), become contaminated and continue seeping downward. The contaminated water may then move through the transport medium (e.g., underground saturated or unsaturated zones) to a well or to a river (biota access location) where it is withdrawn for use in human consumption, crop irrigation, animal watering, etc. Identification of the basic structure of the release/transport mechanisms permits straightforward postulation of barriers that can impede the movement of the transport agent or its associated contamination from one compartment to the next. The following barriers and control mechanisms can be identified using the above example of rainwater infiltration and transport.

- Rainwater infiltration into the waste cell can be reduced by a low-permeability clay cover over a waste disposal trench. This barrier can be controlled through site design and stabilization operations during site closure.

- Water that does enter the trench can be partially inhibited from picking up contamination from the waste by either assuring that the waste container does not permit contact between the waste and water (this may be accomplished through the use of a high integrity container) or by permitting only the disposal of waste that releases radioactivity very slowly upon contact with water. This barrier can be controlled through waste form and packaging.


ENVIRONMENT/WASTE INTERFACE BARRIER
WASTE BARRIER
WASTE/ TRANSFER MEDIUM INTERFACE BARRIER
TRANSFER MEDIUM BARRIER
TRANSFER MEDIUM/ BIOTA ACCESS INTERFACE BARRIER
f_o, f_d
f_w
f_d
f_s
f_s
GROSS TA* INPUT
INPUT BARRIER
NET TA INPUT
TRANSFER BARRIER
GROSS TA OUTPUT
OUTPUT BARRIER
NET TA OUTPUT
DISPERSION/EXCHANGE BARRIER
GROSS TA DISCHARGE
DISCHARGE BARRIER
NET TA DISCHARGE

* TA = TRANSPORT AGENT

REGULATABLE BARRIERS IN THE RELEASE/TRANSPORT SCENARIOS

FIGURE 2.4

- o Release of contaminated water from the trench may then be reduced by another low-permeability clay layer at the bottom of the trench. However, this barrier should be implemented with caution. Otherwise, accumulation of leachate could occur which could eventually fill up the trench and posssibly overflow the trench. This barrier can be controlled through site design.

- o After the water enters the transfer medium (i.e., the soil), the natural geologic barriers that can impede and/or reduce the magnitude of the radionuclide transfer include adsorbtion onto soil particles as the water moves through an underlying strata, dispersion of the radionuclides during migration, and radioactive decay during the contaminant travel through the geologic medium. These barriers can be controlled through site selection.

- o Once the transport agent reaches the biota access location, another mechanism that would reduce the magnitude of the contaminant concentration is dilution with uncontaminated water at the discharge location. For example, the flow rate of a river or the pumping rate of a well affects the degree of dilution achieved. This barrier can also be controlled through site selection.

- o Finally, the point in time at which the groundwater scenario is initiated depends on the waste form and package, site operational procedures, and administrative requirements. For example, the waste may be packaged in a high integrity container. This results in a time-delay factor, due to radioactive decay, that can reduce the magnitude of the source term significantly.

The barrier concepts that have been discussed above can be generalized and applied quantitatively to each release/transport scenario. This may be accomplished by using an interaction factor (denoted by the symbol I) that relates the radionuclide concentration at the biota access location to the radionuclide concentration in the waste:

$$C_a = I \times C_w \qquad (2\text{-}2)$$

where (C_a) and (C_w) are the concentrations of the radionuclide of concern, in units of (Ci/m^3), at the biota access location and in the waste, respectively. The interaction factor (I) can further be compartmentalized in terms of the barriers discussed above:

$$I = f_o \times f_d \times f_w \times f_s \qquad (2\text{-}3)$$

where

f_o = time-delay factor. This factor accounts for all the control mechanisms that increase the time period between the termination of waste disposal at the site and the initiation of contact between the transport agent and the waste.

f_d = site design factor. This factor includes the effects of any engineered barriers designed into the waste disposal operations at the site, plus any site operational practices that may reduce transport.

f_w = waste form and package factor. This factor accounts for the physical and chemical characteristics of the waste, at the time of the initiation of the release/transport scenario, that may inhibit contaminant transfer to the transport agent.

f_s = site selection factor. This factor includes the effects of the natural site environment that contribute to reducing the contaminant concentrations at the biota access location.

These four barrier factors may be used to represent the control mechanisms. Regulation through these factors may be accomplished by either specifying the value required for a given barrier factor, or by defining the characteristics of the barrier needed to achieve the desired effect.

2.2.4 Other Potential Exposure Pathways

The above seven release/transport mechanisms are comparatively the most significant potential pathways to human exposure, and calculational procedures are developed in this report to determine potential human exposure levels resulting from these pathways. The calculational procedures are used to help determine overall performance objectives and technical criteria for near-surface radioactive waste disposal. There are other potential pathways to humans which may be considered during development of the performance objectives and technical criteria, but calculational procedures to estimate specific exposure levels are not developed in this report. These potential exposure pathways include the following:(7)

- Groundwater migration during the operational period of the facility lifespan;
- The bathtub effect -- i.e., filling up of the disposal cells with accumulated leachate and subsequent overflowing;
- Diffusion of radioisotope-tagged decomposition gases through disposal cell covers;
- Dispersion of radioactive material by means of surface runoff or wind dispersion from accidentally contaminated site surfaces and equipment.

All of these potential pathways have been observed at commercial and/or DOE operated disposal facilities.(8-13) The first three pathways are fundamentally caused by site instability problems--that is, by degradation of compressible material within a disposal cell and subsequent subsidence of the disposal cell contents, leading to cracking and slumping of disposal cell covers and increased infiltration of rainwater into the disposal cell. At sites with moderate to high permeability soils, an infiltration problem (resulting from a subsidence problem) can lead to migration of some radionuclides being observed during the operational period of the facility life. This would principally involve very mobile radionuclides such as tritium. However, during site operations the potential for groundwater migration would be monitored and if it occurs, the licensee would take steps to correct the situation. Of more concern is the potential long-term migration of all the radionuclides in the waste after site operations have terminated. At sites with very low permeability soils, an infiltration problem can lead to collection of trench leachate in disposal cells. This leachate would have to be removed and treated during disposal operations.

It has been demonstrated that potential problems of increased infiltration -- migration during the operational period or the bathtub effect -- can be minimized or avoided during the operational period through siting or operational procedures. For example, increased attention paid to compaction of disposal trench covers can greatly reduce the maintenance required during site operations. Of more interest is the long-term stability of a disposal facility, and methods which may be used to ensure this stability. Impacts from the bathtub effect could ultimately include overland flow of a few to some hundreds of gallons of leachate. The principal impact, however, is likely to be the very high costs of remedial action, which could include pumping, treating and solidifying leachate, and restabilization of trench covers. This remedial action could result in an expense to a site owner of better than a million dollars per year, for a number of years.(14) Treatment of leachate could involve airborne or waterborne release of radionuclides.

Past disposal experience indicates that potential diffusion of radioisotopetagged decomposition products such as methane or carbon dioxide can be significantly retarded by facility design and operating practices such as thicker trench covers.(12-13) In any case, generation of decomposition gasses would be reduced through efforts to minimize the degredation of trench contents. In other words, actions undertaken promote site stability and to minimize or eliminate trench subsidence will also serve to significantly reduce generation of radioisotope-tagged decomposition gases.

Potential operational impacts due to run-off or wind dispersion of contaminated site surfaces are site specific and would be addressed as part of the licensing of individual disposal facilities, and calculational procedures to estimate the levels of these potential impacts are not developed in this report. In any case, these impacts can be reduced to negligible levels through strict on-site contamination control at a disposal facility, and through better attention paid to packaging of wastes for transportation. In the past, one of the most significant contributor to on-site contamination has been accidental spillage of trench leachate during pumping for treatment. In addition, another significant contributor to on-site contamination has been accidental spillage of low-level liquids which were at one time delivered to some disposal facilities for solidification and disposal. More recently, however, this practice has been discontinued and all disposal facilities accept only solid wastes for disposal. Probably another cause for on-site contamination is through excessive free-standing liquids in (and leaking out of) disposal containers.

Potential intrusion by deep rooted plants or burrowing animals through disposal cell covers is another potential pathway. This intrusion could potentially result in increased human exposures by three general mechanisms:

(1) surfacing of radioactive material which could then be dispersed by wind or water,

(2) human consumption of contaminated plants or animals, or

(3) increasing rainwater percolation into the disposed waste through root channels and animal burrows, thereby potentially increasing radionuclide migration through groundwater.

These potential exposures, particularly the first two mechanisms, are difficult to quantify. Past occurrences of plant and animal intrusion at existing disposal facilities, potential exposure pathways to humans, and methods to reduce or preclude such intrusion are site specific and are not quantified in the generic analysis developed in this report. In any case, the major impact of deep-rooted plant and burrowing animal intrusion at a disposal facilty is likely to be an increase in the potential for groundwater migration. This potential effect on groundwater migration is quantitatively considered in this report (see Section 3.5). However, for perspective, a brief discussion based on reference 13 of potential deep-rooted plant and animal intrusion is presented below.

For uptake by vegetation, a biomass model, using the parameters of the ecosystem that follow the generation and transfer of biomass, assumes that 0.2 percent of the root mass of a mature tree is below 1.5 m from the soil surface with the uptake linearly proportional to this fraction.(13) An evaluation of uptake for wastes containing plutonium at a concentration of 10 nCi/g was performed and yielded a concentration $8x10^{-6}$ nCi/g at the soil surface after 5000 years.(13) From these results, reference 13 concludes that this mechanism is unlikely to produce surface concentrations exceeding the original waste concentrations. Therefore, the intruder scenarios will be the limiting scenarios.

The other mechanism is potential animal or insect intrusion. The depths of burrows or tunnels for some typical animals and insects are given below:(13)

Species	Maximum Typical Burrow and Tunnel Depth
Harvester Ant	3 m
Moles	1.2 m
Pocket Gopher	0.6 m
Pocket Mouse	1.6 m
Deer Mouse	0.6 m
Field Mouse	0.6 m
Earthworms	0.5 m

As can be seen, the probability of animals other than harvester ants reaching the wastes with a two meter cover is low.(13) Even after significant erosion of the waste cover, the surface concentrations will be lower than the wastes and the doses will be controlled by the pathway of people living on the area after the wastes are exposed by erosion.(13) This implies that the intruder scenarios will again be the limiting scenarios. In any case, burrowing animals that may be found in various regions of the continental U.S. are discussed in Appendix C for four hypothetical disposal facility sites.

2.3 Pathway Dose Conversion Factors

This section considers the pathway dose conversion factors (PDCF's) introduced in equation 2-1. It presents a background on dose calculational procedures, presents detailed pathway diagrams for the seven pathways considered in Section 2.2, discusses the biota access locations, and gives PDCF values for the seven pathways of concern for the seven human organs and 23 radionuclides selected for consideration in this report.

2.3.1 Background

The use of the pathway dose conversion factors (PDCF's) in the calculational methodology is straightforward. It is multiplied by the radionuclide concentration at the biota access location(s) (C_a) to obtain the human exposures:

$$H = \text{PDCF} \times C_a \qquad (2\text{-}1)$$

where PDCF stands for the pathway dose conversion factor in units of millirem (mrem) per Ci/m^3 for the acute exposure scenarios and in units of mrem/year per Ci/m^3 for the chronic exposure scenarios. The radionuclide concentration at the biota access location (C_a) is in units of Ci/m^3.

In this report, for acute exposures, H will be taken as the dose in mrem, received during 50 years following a one-year exposure to the radioactive material; and for chronic exposures, H will be taken as the dose rate in mrem/year, received during the 50th year of an exposure period lasting 50 years. These two definitions result in use of the same fundamental dose conversion factors for the chronic and acute scenarios. Hereinafter, the qualifier equivalent is assumed to be implicit in the term dose; similarly, the dose equivalent rate will be referred to as the dose rate.

Some of the acute exposure scenarios last for much shorter periods than one year. However, for calculational convenience all acute exposures will be assumed to last one year. A correction factor, used to normalize acute exposure periods to the one-year reference value, will be incorporated into the release/transport portion of the scenario, usually into the site selection factor f_s, as appropriate to the scenario.

Use of the PDCF requires a clear quantitative pathway model, which is arrived at through the following steps:(3)

(1) defining the objective of the modelling effort,

(2) forming the block diagram of the system identifying the ecological and environmental compartments,

(3) identifying and quantitatively determining the "translocation" parameters of the system,

(4) predicting the response of the system to the input parameters by using either the concentration factor (CF) method or the systems analysis (SA) method, and

(5) analyzing this response for the critical radionuclides and pathways and the effects of parameter uncertainties.

These steps are straightforward, except for the definition of the "translocation" parameters (which are referred to as transfer factors in this work) and the use of either the CF or the SA methods to predict the response of the system. These are briefly summarized below.

The transfer factors are simply the transfer functions or coefficients that express contaminant exchange between the various environmental compartments of the pathway diagram -- e.g., animal bioaccumulation factors, plant uptake factors, etc. A survey of the literature yields a considerable range of values for these parameters dependent on the human environment. One may obtain preliminary values from laboratory and field experiments, but these should be refined by observations in the actual system. Values for the transfer factors utilized in this work are detailed in Appendices A and B.

In order to mathematically model the movement of a radionuclide from its source to its uptake by a human population, two modeling systems may be used. They are referred to as the CF and SA methods. Both require the conceptualization of the actual system as a series of compartments through which the radionuclides pass (e.g., as in Figures 2.1 and 2.2). The movement of radionuclides from one compartment to the next (e.g., soil to crops) is characterized by a transfer pathway that may be quantified by a mathematical representation of the transfer mechanism. The two systems differ primarily in the degree of complexity to which the transfer mechanisms are treated.

In the CF method, time-dependent behavior is neglected. In other words, chronic releases of a contaminant are treated as time-averaged concentrations (usually on an annual basis), and acute releases are treated as time integrated quantities. The transfer pathway is thus reduced to a single factor that, when multiplied by the concentration in a given compartment, yields the concentration in the next compartment. The result is that a very simple series of computations can trace the radionuclide concentration through the various compartments postulated for the model.

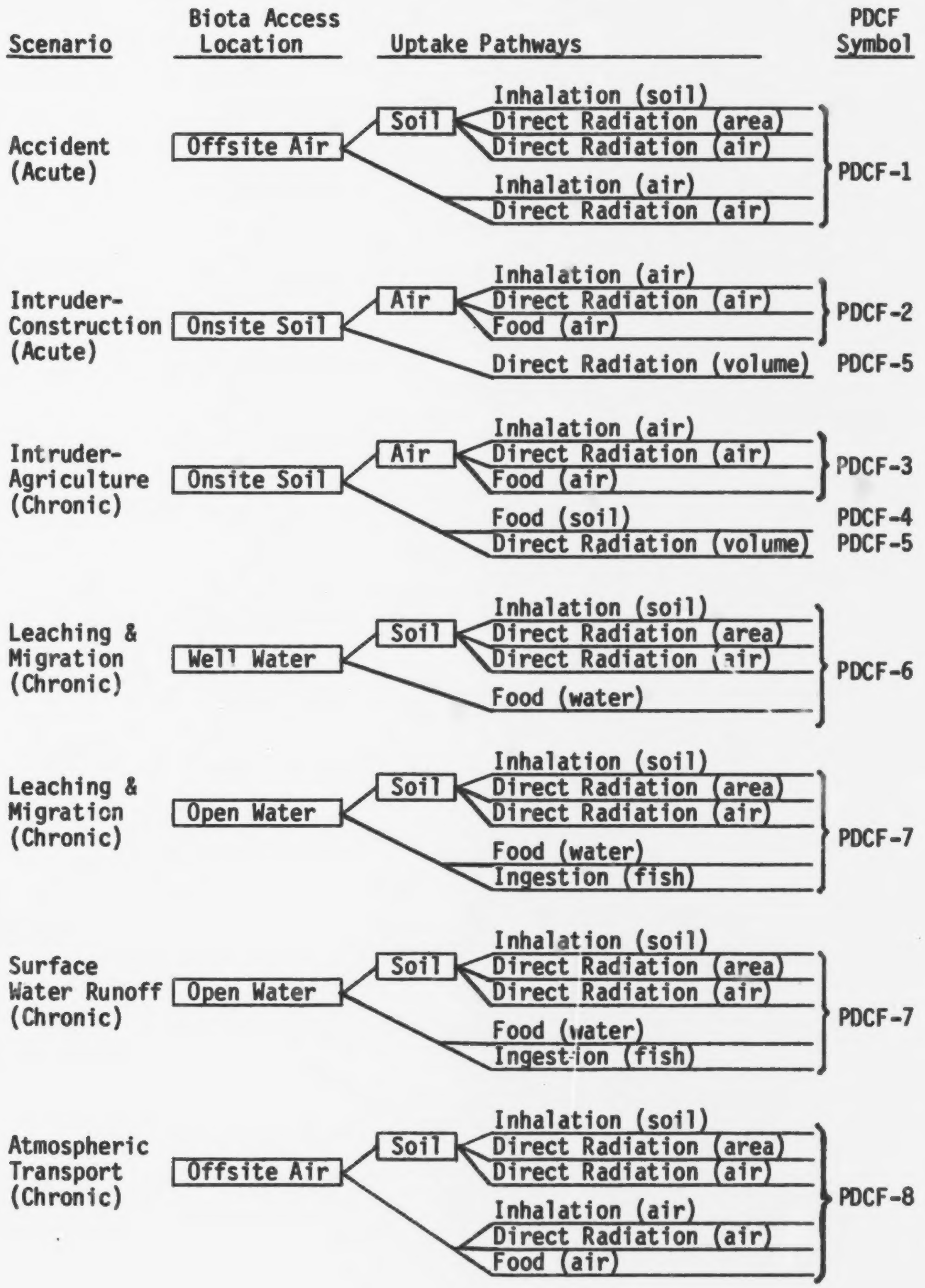
The SA method is utilized in systems where the compartment transfer mechanisms are time dependent. An example of this would be the release of radionuclides into a soil where chemical reactions may take place that result in irreversible fixation (reversible sorption is assumed in this work). This represents a time-dependent concentration reduction mechanism other than simple dilution and can be modeled with the SA method using reaction rate data. The end result of using the SA method is a series of differential equations that must be solved in order to follow the dynamics of radionuclide movement through the model system.

The choice between the two methodologies is generally based on the state of knowledge of radionuclide movement through a transfer pathway. If little is known about the dynamics of the system, the CF method must be used to obtain first order estimations of concentrations at biota access locations. If transfer mechanisms are known in sufficient detail and time-dependent factors are important, then the SA method should be used. Because of the generic nature of the impact analysis methodology, the CF method has been utilized throughout this report.

2.3.2 Pathways

The PDCF's for the pathways indicated in Figure 2.3 are the total dose conversion factors for the individual pathways of importance in contributing to human exposures from concentrations of radionuclides at biota access locations. The individual pathways that comprise the total pathways are shown in Figure 2.5. Also shown are the PDCF symbols for groups of uptake pathways that will be utilized in this report. These individual uptake pathways that comprise the total pathways are discussed below.

Figure 2.5 . Details of Uptake Pathways


Scenario
Biota Access Location
Uptake Pathways
PDCF Symbol
Accident (Acute)
Offsite Air
Soil
Inhalation (soil)
Direct Radiation (area)
Direct Radiation (air)
Inhalation (air)
Direct Radiation (air)
PDCF-1
Intruder-Construction (Acute)
Onsite Soil
Air
Inhalation (air)
Direct Radiation (air)
Food (air)
PDCF-2
Direct Radiation (volume)
PDCF-5
Intruder-Agriculture (Chronic)
Onsite Soil
Air
Inhalation (air)
Direct Radiation (air)
Food (air)
PDCF-3
Food (soil)
PDCF-4
Direct Radiation (volume)
PDCF-5
Leaching & Migration (Chronic)
Well Water
Soil
Inhalation (soil)
Direct Radiation (area)
Direct Radiation (air)
Food (water)
PDCF-6
Leaching & Migration (Chronic)
Open Water
Soil
Inhalation (soil)
Direct Radiation (area)
Direct Radiation (air)
Food (water)
Ingestion (fish)
PDCF-7
Surface Water Runoff (Chronic)
Open Water
Soil
Inhalation (soil)
Direct Radiation (area)
Direct Radiation (air)
Food (water)
Ingestion (fish)
PDCF-7
Atmospheric Transport (Chronic)
Offsite Air
Soil
Inhalation (soil)
Direct Radiation (area)
Direct Radiation (air)
Inhalation (air)
Direct Radiation (air)
Food (air)
PDCF-8

As presented in Figure 2.5, all of the scenarios involve a secondary biota access location resulting from the primary access location. Two of the scenarios have four uptake pathways, four have five, and one has six, yielding a total of 34 uptake pathways. However, of these 34 uptake pathways only 9 are unique types of uptake pathways, if only the uptake mode and transport agents are considered. These nine distinct types of uptake pathways are described in Table 2.2.

Only primary and secondary biota access locations are considered in the determination of these uptake pathways. The effects of possible tertiary access locations, such as air contaminated due to natural suspension of radioactivity from soil which is originally contaminated from deposition of radioactivity from air, are not considered. These effects are considered, however, in the selection of transfer factors between the uptake pathways.

The accident scenario includes offsite air as the primary access location leading to two uptake pathways: inhalation (air), and direct radiation (air); it also includes soil contaminated by radionuclide deposition as the secondary access location leading to three more uptake pathways: inhalation (soil), direct radiation (area), and direct radiation (air). Since the exposure period is acute, the food (air) uptake pathway has been excluded from this scenario. However, the direct radiation (air) uptake pathway is included in the secondary access location in addition to the direct radiation (air) from the primary access location.

The construction scenario includes onsite soil as the primary access location leading only to the direct radiation (volume) uptake pathway. The scenario also includes onsite air as the secondary access location leading to three uptake pathways: inhalation (air), direct radiation (air), and food (air). Although the exposure period is acute, the food (air) uptake pathway is included with a modification to account for non-equilibrium deposition and root-uptake conditions.

TABLE 2-2 . Access Location-to-Human Pathway Descriptions

Pathway Designation	Description
Food (soil)	This uptake pathway includes a total of three subpathways and denotes uptake of radionuclides originating in plants via soil-to-root transfer from contaminated soil: plant-to-human plant-to-animal-to-human plant-to-animal-to-product-to-human
Food (air)	This uptake pathway includes a total of six subpathways and includes the above three food (soil) subpathways resulting from uptake of radionuclides originating on plant surfaces via deposition from contaminated air and the same three food (soil) subpathways resulting from fallout contamination of the ground.
Food (water)	This uptake pathway includes a total of nine subpathways and includes all the food (soil) pathways resulting from radionuclides originating on plant surfaces via irrigation deposition from contaminated water and from irrigation contamination of the ground. The following three subpathways in addition to the plant pathways are added: water-to-human water-to-animal-to-human water-to-animal-to-product-to-human
Ingestion (fish)	Uptake of radionuclides from eating fish caught in contaminated open water.
Inhalation (air)	Uptake of radionuclides from breathing air contaminated due to suspension of contaminated soil particulates by human activities.
Inhalation (soil)	Uptake of radionuclides from breathing air contaminated due to natural suspension and volatilization of surface soil.
Direct Radiation (volume)	Direct exposure to ionizing radiation from standing on ground homogeneously contaminated.
Direct Radiation (area)	Direct exposure to ionizing radiation from standing on ground whose surface is contaminated.
Direct Radiation (air)	Direct exposure to ionizing radiation from standing in air homogeneously contaminated.

The agriculture scenario also includes onsite soil as the primary access location; however, the food (soil) uptake pathway is included in this case in addition to the direct radiation (volume) uptake pathway. The scenario also includes onsite air as the secondary access location leading to the same three uptake pathways as the construction scenario secondary access location: inhalation (air), direct radiation (air), and food (air). However, in this case, chronic conditions are assumed to prevail, and equilibrium conditions are assumed for the food (air) uptake pathway.

The next three scenarios involving water are very similar. As a matter of fact, the two open water scenarios are identical. The only additional uptake pathway in the open water scenario as opposed to the well water scenario is the ingestion (fish) pathway. This pathway is included since the bioaccumulation factors for several fish species are significantly greater than unity. However, direct radiation exposure to contaminated water was omitted; it turned out to result in negligible additional exposures (less than 0.1%) when compared with the other uptake pathways.

The last scenario, the atmospheric transport scenario, is identical with the accident scenario with the addition of the food (air) uptake pathway to the primary access location. In this case, however, the exposure is assumed to be chronic as opposed to acute for the accident scenario.

As can be seen from Figure 2.5, five of the release/transport/pathway scenarios are represented by a single PDCF. However, the other two scenarios involving intrusion are more complex since different transfer factors are applicable to the individual uptake components of the intruder-construction and intruder-agriculture scenarios. The differences in the transfer factors result from either differences in the mechanism mobilizing the radioactivity or differences in the access locations.

2.3.3 Pathway Dose Conversion Factor Tables

This section presents the calculated values for the eight pathway dose conversion factors (PDCF's) identified in Figure 2.5 which will be utilized in the radiological impact calculations. Seven human organs are considered in this report for each radionuclide and each pathway: total body, bone, kidney, thyroid, liver, lung, and gastrointestinal (GI) tract. These pathway dose conversion factors have been derived from the 9 independent pathways presented in Table 2-2. The information utilized in the calculation of the PDCF's includes human physiological parameters (e.g., breathing rates, nuclide metabolism), dietary intakes, and nuclide-specific food chain transfer rates.(15-26) A brief discussion of the calculational methodology is presented below. Details of the calculation (including the computer code used in the calculation) can be found in Appendix B.

The PDCF's have been calculated for 23 radionuclides. These radionuclides have been selected based on the discussion and considerations presented in reference 3. Uptake pathway data on other radionuclides is presented in Appendix B, and calculation of the PDCF's for other radionuclides is straightforward. The radionuclides considered in this report are summarized in Table 2-3.

All the PDCF's are calculated based on five sets of fundamental dose conversion factors. Two of the sets include DCF's for determing the inhalation 50-year committed dose in units of mrem per pCi inhaled and the ingestion 50-year committed dose in units of mrem per pCi ingested. Three different direct radiation exposure DCF's are used depending on the particular biota access location considered. These include DCF's for volume contamination of soil (mrem/year per pCi/m^3), surface contamination of soil (mrem/year per pCi/m^2), and air contamination (mrem/year per pCi/m^3). These fundamental DCF's are a function of the radionuclide of concern and the organ receiving the dose. A brief description of the fundamental DCF's is provided below.

TABLE 2-3 . Radionuclides Considered in Analyses

Isotope	Half Life (years)	Radiation Emitted	Principal Means of Production
H-3	12.3	β	Fission; Li-6 (n, α)
C-14	5730	β	N-14 (n, p)
Fe-55	2.60	X-rays	Fe-54 (n, γ)
Co-60	5.26	β , γ	Co-59 (n, γ)
Ni-59	80,000	X-rays	Ni-58 (n, γ)
Ni-63	92	β	Ni-62 (n, γ)
Sr-90	28.1	β	Fission
Nb-94	20,000	β , γ	Nb-93 (n, γ)
Tc-99	$2.12x10^5$	β	Fission; Mo-98 (n, γ) Mo-99 (β^-)
I-129	$1.17x10^7$	β , γ	Fission
Cs-135	$3.0x10^6$	β	Fission; daughter Xe-135
Cs-137	30.0	β , γ	Fission
U-235	$7.1x10^8$	α , γ	Natural
U-238	$4.51x10^9$	α , γ	Natural
Np-237	$2.14x10^6$	α , γ	U-238 (n, 2n) U-237 (β^-)
Pu-238	86.4	α , γ	Np-237 (n, γ) Np-238 (β^-); daughter Cm-242
Pu-239	24,400	α , γ	U-238 (n, γ) U-239 (β^-) Np-239 (β^-)
Pu-240(a)	6,580	α , γ	Multiple n-capture
Pu-241	13.2	α , β , γ	Multiple n-capture
Pu-242	$2.79x10^5$	α	Multiple n-capture; daughter Am-242
Am-241	458	α , γ	Daughter Pu-241
Am-243	7950	α , γ	Multiple n-capture
Cm-243	32	α , γ	Multiple n-capture
Cm-244	17.6	α , γ	Multiple n-capture

(a) Pu-239 and Pu-240 are considered as a single radionuclide in the impact analyses since they generally cannot be radiochemically distinguished. The activity of Pu-240 is added to that of Pu-239.

The most comprehensive compilation of information on the initial deposition of inhaled particles in the respiratory tract was published by the ICRP Task Group on Lung Dynamics in 1966.(15) This report includes an anatomical description of the respiratory tract, characteristics of particle size distribution, and physiological parameters describing the inhalation process. Based on these parameters, a quantitative model for initial respiratory tract deposition was developed. The report also describes a lung clearance model that is more comprehensive than those used previously; it is based on extensive studies with laboratory animals and results of human contamination cases and it also incorporates the major clearance processes. With this model, various retention characteristics are described for compounds of all the elements in the periodic table.

The complete lung model, as proposed by the Task Group(15,16) has been utilized in this report to calculate the fundamental inhalation dose conversion factors. This model permits a more realistic calculation of radiation dose to the human respiratory tract from inhaled radioactivity than does the initial ICRP lung model.(17) The inhalation DCF's utilized in this report have been obtained by utilizing a computer code called DACRIN.(18) A description of this code is summarized in Appendix B.

For the fundamental ingestion DCF's, existing models that are presented in several documents are considered to be reasonable representations of the human organism,(17,19,20) and ingestion DCF's given in reference 20 have been utilized in this report.

The need to use three different fundamental direct radiation exposure DCF's arises from the geometry of exposure, and the attenuation and buildup afforded by the different contaminated media. These considerations are detailed in many references.(17,20,21) In this work, fundamental direct radiation (volume) DCF's have been calculated based on the equations presented in reference 21 and the emitted gamma energy characteristics of the radionuclides considered.(22) The details of the calculations can be found in Appendix B. For the fundamental direct radiation (area) and the direct radiation (air) DCF's, the tables given in reference 23, which include effects of beta radiation in addition to gamma radition, are utilized.

The PDCF's calculated based on these fundamental dose conversion factors and pathway uptake factors (i.e., the translocation parameters) obtained from several references(4,6,19,24-26) are presented in Tables 2-4 through 2-11. The most recent information available on the transuranic translocation parameters has been utilized in these computations (see Appendix B).

The I-129 PDCF for thyroid requires further discussion. The calculated I-129 PDCF's in Tables 2-4 through 2-11 do not take into account the dilution of I-129 with natural iodine. Environmental concentrations of I-129 with respect to natural iodine (I-127) has been the subject of several studies.(27-29) One study indicates that around existing nuclear facilities, the atom ratio of I-129 to that of I-127 measured in biota ranges up to 3.9×10^{-5} in thyroid tissues of animals other than bovine (deer around the Hanford Reservation), and up to 1.7×10^{-6} in bovine thyroid tissues (around Northeastern Oregon).(27) In another study, bovine thyroid tissues have been observed to have an I-129/I-127 atom ratio of 4.5×10^{-7} around the Savannah River Plant.(28) It has also been estimated that the I-129/I-127 ratio may possibly be as high as 0.0035 in the waste/soil mixture in a disposal site.(29) This calculation assumes the disposal of waste from 25 reactors and a conservatively low average I-127 concentration in soil of 1 ppm (parts per million). Reference 29 further calculates that if this atom ratio is below 0.02 it would not be possible to exceed the existing dose guidelines for thyroid exposures.

Experimental environmental data and calculations such as the above have led some investigators in the past to utilize the total body dose

TABLE 2-4 . Pathway Dose Conversion Factor - 1

ACCIDENT

	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	1.25E+09	5.19E+07	1.25E+09	1.25E+09	1.25E+09	1.25E+09	5.19E+07
C-14	3.17E+09	1.40E+10	3.17E+09	3.17E+09	3.17E+09	3.17E+09	2.53E+09
FE-55	1.81E+10	1.89E+10	2.41E+10	1.61E+10	1.61E+10	2.08E+11	1.93E+10
CO-60	2.36E+12	2.34E+12	2.35E+12	2.34E+12	2.34E+12	2.63E+13	2.50E+12
NI-59	3.70E+10	9.38E+10	5.06E+10	2.58E+10	2.58E+10	5.78E+10	2.85E+10
NI-63	3.06E+10	9.60E+11	6.58E+10	1.56E+08	1.56E+08	8.82E+10	7.44E+09
SR-90	2.42E+13	9.62E+13	1.67E+11	1.67E+11	1.67E+11	1.98E+11	1.89E+11
NB-94	6.10E+11	5.11E+11	6.11E+11	6.10E+11	6.11E+11	1.33E+12	6.84E+11
TC-99	1.18E+09	9.68E+08	2.28E+09	7.60E+08	2.00E+10	7.40E+09	7.88E+09
I-129	9.14E+11	8.52E+11	8.52E+11	5.13E+13	8.52E+11	8.57E+11	8.52E+11
CS-135	2.37E+10	9.65E+10	8.85E+10	5.08E+08	3.33E+10	1.49E+10	1.00E+09
CS-137	4.50E+11	6.34E+11	7.78E+11	2.42E+11	4.26E+11	3.30E+11	2.44E+11
U-235	2.06E+12	3.06E+13	2.21E+11	2.21E+11	7.26E+12	3.36E+15	5.17E+11
U-238+D	1.69E+12	2.88E+13	1.45E+10	1.45E+10	6.57E+12	3.12E+15	2.55E+11
NP-237+D	5.20E+14	1.20E+16	1.12E+15	1.34E+11	3.84E+15	3.60E+14	3.74E+11
PU-238	2.00E+14	4.08E+15	2.80E+15	1.92E+10	8.80E+14	4.08E+15	3.31E+11
PU-239	2.24E+14	4.80E+15	3.12E+15	7.40E+09	9.60E+14	3.84E+15	3.03E+11
PU-241	3.04E+12	7.44E+13	4.56E+13	4.78E+07	1.44E+13	6.80E+12	5.57E+09
PU-242	2.16E+14	4.48E+15	3.04E+15	1.44E+10	9.60E+14	3.68E+15	2.94E+11
AM-241	5.04E+14	7.12E+15	6.64E+15	7.87E+10	3.84E+15	4.24E+14	3.59E+11
AM-243	4.96E+14	7.04E+15	6.48E+15	9.10E+10	3.76E+15	4.00E+14	3.63E+11
CM-243	3.84E+14	6.16E+15	5.60E+15	2.44E+11	1.76E+15	4.40E+14	5.48E+11
CM-244	2.80E+14	4.40E+15	4.16E+15	1.71E+10	1.28E+15	4.40E+14	3.05E+11

TABLE 2-5 . Pathway Dose Conversion Factor - 2

CONSTRUCT	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	1.17E+10	5.19E+07	1.17E+10	1.17E+10	1.17E+10	1.17E+10	1.05E+10
C-14	6.68E+10	3.32E+11	6.68E+10	6.68E+10	6.68E+10	6.68E+10	6.61E+10
FE-55	9.28E+09	4.82E+10	3.94E+10	5.08E+07	5.08E+07	2.10E+11	2.12E+10
CO-60	1.24E+11	2.28E+10	7.60E+10	2.28E+10	2.28E+10	2.40E+13	8.59E+11
NI-59	3.87E+10	2.33E+11	8.13E+10	5.98E+07	5.98E+07	3.21E+10	1.44E+10
NI-63	1.04E+11	3.15E+12	2.18E+11	1.56E+08	1.56E+08	8.82E+10	3.91E+10
SR-90	5.52E+13	2.23E+14	1.76E+09	1.76E+09	1.76E+09	3.30E+10	3.69E+12
NB-94	1.39E+10	1.51E+10	1.45E+10	1.32E+10	1.45E+10	7.33E+11	4.43E+11
TC-99	2.25E+09	3.64E+09	6.26E+09	7.60E+08	7.00E+10	7.74E+09	1.38E+11
I-129	2.00E+12	6.88E+11	5.91F+11	1.57E+15	1.27E+12	6.37E+09	9.45E+10
CS-135	1.57E+11	4.21E+11	3.88E+11	5.08E+08	1.47E+11	4.89E+10	8.01E+09
CS-137	1.40E+12	1.72E+12	2.35E+12	1.53E+09	8.01E+11	2.94E+11	3.92E+10
U-235	2.64E+12	4.36E+13	1.59E+09	1.59E+09	1.01E+13	3.36E+15	1.59E+12
U-238+D	2.43E+12	4.15E+13	8.57E+07	8.57E+07	9.45E+12	3.12E+15	1.15E+12
NP-237+D	5.21E+14	1.20E+16	1.12E+15	8.40E+08	3.85E+15	3.60E+14	1.55E+12
PU-238	2.00E+14	4.09E+15	2.80E+15	8.87E+07	8.81E+14	4.08F+15	1.51E+12
PU-239	2.24E+14	4.81E+15	3.12E+15	5.17E+07	9.61E+14	3.84E+15	1.39E+12
PU-241	3.05E+12	7.47E+13	4.56E+13	4.78E+07	1.44E+13	6.80E+12	2.86E+10
PU-242	2.16E+14	4.49E+15	3.04E+15	6.93E+07	9.61E+14	3.68E+15	1.35E+12
AM-241	5.05E+14	7.13E+15	6.64E+15	3.80E+08	3.85E+15	4.24E+14	1.51E+12
AM-243	4.97E+14	7.05E+15	6.48E+15	6.09E+08	3.77E+15	4.00E+14	1.71E+12
CM-243	3.85E+14	6.17E+15	5.60E+15	2.26E+09	1.76E+15	4.40E+14	1.59E+12
CM-244	2.80E+14	4.41E+15	4.16E+15	7.23E+07	1.28E+15	4.40E+14	1.53E+12

TABLE 2-6 . Pathway Dose Conversion Factor - 3

AGRICULTUR

	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	4.45E+10	5.19E+07	4.45E+10	4.45E+10	4.45E+10	4.45E+10	4.33E+10
C-14	2.66E+11	1.33E+12	2.66E+11	2.66E+11	2.66E+11	2.66E+11	2.65E+11
FE-55	3.22E+10	1.90E+11	1.38E+11	5.08E+07	5.08E+07	2.64E+11	7.75E+10
CO-60	3.70E+11	2.28E+10	1.87E+11	2.28E+10	2.28E+10	2.40E+13	2.95E+12
NI-59	1.25E+11	7.48E+11	2.58E+11	5.98E+07	5.98E+07	3.21E+10	5.08E+10
NI-63	3.34E+11	1.00E+13	6.93E+11	1.56E+08	1.56E+08	8.82E+10	1.38E+11
SR-90	1.53E+14	6.21E+14	1.76E+09	1.76E+09	1.76E+09	3.30E+10	1.52E+13
NB-94	1.40E+10	1.55E+10	1.47E+10	1.32E+10	1.46E+10	7.33E+11	1.56E+12
TC-99	5.61E+09	1.20E+10	1.87E+10	7.60E+08	2.27E+11	8.80E+09	5.45E+11
I-129	8.06E+12	2.84E+12	2.44E+12	6.33E+15	5.24E+12	6.37E+09	3.87E+11
CS-135	5.73E+11	1.44E+12	1.33E+12	5.08E+08	5.02E+11	1.55E+11	3.00E+10
CS-137	5.12E+12	5.87E+12	8.03E+12	1.53E+09	2.73E+12	9.35E+11	1.49E+11
U-235	5.15E+12	8.50E+13	1.59E+09	1.59E+09	1.98E+13	3.36E+15	5.62E+12
U-238+D	4.77E+12	8.11E+13	8.57E+07	8.57E+07	1.85E+13	3.12E+15	3.99E+12
NP-237+D	5.24E+14	1.21E+16	1.13E+15	8.40E+08	3.87E+15	3.60E+14	5.65E+12
PU-238	2.01E+14	4.13E+15	2.81E+15	8.87E+07	8.85E+14	4.08E+15	5.28E+12
PU-239	2.25E+14	4.85E+15	3.13E+15	5.17E+07	9.66E+14	3.84E+15	4.83E+12
PU-241	3.06E+12	7.55E+13	4.57E+13	4.78E+07	1.45E+13	6.80E+12	1.01E+11
PU-242	2.17E+14	4.53E+15	3.05E+15	6.93E+07	9.65E+14	3.68E+15	4.72E+12
AM-241	5.08E+14	7.18E+15	6.66E+15	3.80E+08	3.87E+15	4.24E+14	5.36E+12
AM-243	5.00E+14	7.10E+15	6.50E+15	6.09E+08	3.79E+15	4.00E+14	6.22E+12
CM-243	3.87E+14	6.20E+15	5.62E+15	2.26E+09	1.77E+15	4.40E+14	5.63E+12
CM-244	2.82E+14	4.43E+15	4.17E+15	7.23E+07	1.29E+15	4.40E+14	5.43E+12

TABLE 2-7 . Pathway Dose Conversion Factor - 4

FOOD

	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	5.99E+04	0.	5.99E+04	5.99E+04	5.99E+04	5.99E+04	5.99E+04
C-14	3.72E+05	1.86E+06	3.72E+05	3.72E+05	3.72E+05	3.72E+05	3.72E+05
FE-55	3.48E+01	2.16E+02	1.49E+02	0.	0.	8.33E+01	8.57E+01
CO-60	5.27E+03	0.	2.39E+03	0.	0.	0.	4.49E+04
NI-59	3.69E+03	2.21E+04	7.59E+03	0.	0.	0.	1.56E+03
NI-63	9.88E+03	2.95E+05	2.04E+04	0.	0.	0.	4.26E+03
SR-90	3.76E+06	1.53E+07	0.	0.	0.	0.	4.42E+05
NB-94	2.12E+00	7.08E+00	3.94E+00	0.	3.89E+00	0.	2.39E+04
TC-99	1.53E+03	3.82E+03	5.68E+03	0.	7.15E+04	4.83E+02	1.86E+05
I-129	2.19E+04	7.77E+03	6.68E+03	1.72E+07	1.44E+04	0.	1.06E+03
CS-135	9.50E+03	2.32E+04	2.14E+04	0.	8.10E+03	2.43E+03	5.01E+02
CS-137	8.49E+04	9.48E+04	1.30E+05	0.	4.40E+04	1.46E+04	2.51E+03
U-235	1.44E+04	2.38E+05	0.	0.	5.55E+04	0.	2.32E+04
U-238+D	1.35E+04	2.28E+05	0.	0.	5.20E+04	0.	1.63E+04
NP-237+D	1.64E+04	4.07E+05	3.53E+04	0.	1.22E+05	0.	2.36E+04
PU-238	1.14E+03	4.52E+04	6.37E+03	0.	4.87E+03	0.	4.85E+03
PU-239	1.27E+03	5.23E+04	7.05E+03	0.	5.39E+03	0.	4.43E+03
PU-241	2.21E+01	1.10E+03	5.61E+01	0.	1.02E+02	0.	9.31E+01
PU-242	1.22E+03	4.85E+04	6.78E+03	0.	5.19E+03	0.	4.34E+03
AM-241	3.60E+04	5.45E+05	1.92E+05	0.	2.71E+05	0.	4.94E+04
AM-243	3.53E+04	5.44E+05	1.85E+05	0.	2.65E+05	0.	5.79E+04
CM-243	1.11E+04	1.90E+05	7.15E+04	0.	5.20E+04	0.	2.32E+04
CM-244	8.52E+03	1.43E+05	6.15E+04	0.	3.98E+04	0.	2.24E+04

TABLE 2-8 . Pathway Dose Conversion Factor - 5

DIR. GAMMA

	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	0.	0.	0.	0.	0.	0.	0.
C-14	0.	0.	0.	0.	0.	0.	0.
FE-55	0.	0.	0.	0.	0.	0.	0.
CO-60	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07	1.54E+07
NI-59	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03	6.20E+03
NI-63	0.	0.	0.	0.	0.	0.	0.
SR-90	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04	3.06E+04
NB-94	9.63E+06	9.63E+06	9.63E+06	9.63E+06	9.63E+06	9.63E+06	9.63E+06
TC-99	0.	0.	0.	0.	0.	0.	0.
I-129	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04	1.92E+04
CS-135	0.	0.	0.	0.	0.	0.	0.
CS-137	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06	3.50E+06
U-235	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05	1.50E+05
U-238+D	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03	5.16E+03
NP-237+D	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.56E+04	6.56E+04
PU-238	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01	1.93E+01
PU-239	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01	9.39E+01
PU-241	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01	3.43E-01
PU-242	0.	0.	0.	0.	0.	0.	0.
AM-241	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04	7.71E+04
AM-243	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05	1.86E+05
CM-243	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05	3.82E+05
CM-244	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01	5.64E+01

TABLE 2-9 . Pathway Dose Conversion Factor - 6

WELL WATER

	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	2.37E+06	1.42E-01	2.37E+06	2.37E+06	2.37E+06	2.37E+06	2.37E+06
C-14	1.44E+07	7.21E+07	1.44E+07	1.44E+07	1.44E+07	1.44E+07	1.44E+07
FE-55	2.73E+06	1.24E+07	8.86E+06	8.61E+05	8.61E+05	5.33E+06	5.45E+06
CO-60	1.43E+08	1.24E+08	1.33E+08	1.24E+08	1.24E+08	1.24E+08	2.89E+08
NI-59	8.54E+06	4.42E+07	1.61E+07	1.38E+06	1.38E+06	1.38E+06	4.41E+06
NI-63	1.92E+07	5.71E+08	3.96E+07	4.28E-01	4.28E-01	2.42E+02	8.26E+06
SR-90	7.61E+09	3.10E+10	8.83E+06	8.83E+06	8.83E+06	8.83E+06	9.04E+08
NB-94	3.19E+07	3.20E+07	3.19E+07	3.19E+07	3.19E+07	3.19E+07	1.47E+08
TC-99	3.60E+05	8.96E+05	1.33E+06	2.08E+00	1.68E+07	1.13E+05	4.36E+07
I-129	4.18E+07	1.72E+07	1.53E+07	2.99E+10	2.87E+07	3.64E+06	5.48E+06
CS-135	3.32E+07	8.09E+07	7.47E+07	1.39E+00	2.83E+07	8.46E+06	1.75E+06
CS-137	3.09E+08	3.44E+08	4.65E+08	1.29E+07	1.66E+08	6.39E+07	2.16E+07
U-235	2.07E+08	3.24E+09	1.18E+07	1.18E+07	7.64E+08	2.10E+07	3.26E+08
U-238+D	1.83E+08	3.09E+09	7.74E+05	7.74E+05	7.05E+08	9.32E+06	2.22E+08
NP-237+D	2.31E+08	5.55E+09	4.88E+08	7.13E+06	1.67E+09	8.11E+06	3.26E+08
PU-238	7.02E+07	2.74E+09	3.93E+08	1.03E+06	2.97E+08	1.22E+07	2.94E+08
PU-239	7.77E+07	3.17E+09	4.34E+08	3.93E+05	3.28E+08	1.09E+07	2.68E+08
PU-241	1.34E+06	6.64E+07	3.51E+06	1.31E-01	6.18E+06	1.86E+04	5.62E+06
PU-242	7.52E+07	2.94E+09	4.18E+08	7.67E+05	3.17E+08	1.09E+07	2.63E+08
AM-241	2.25E+08	3.34E+09	1.19E+09	4.19E+06	1.66E+09	5.35E+06	3.05E+08
AM-243	2.21E+08	3.34E+09	1.15E+09	4.94E+06	1.63E+09	5.93E+06	3.57E+08
CM-243	1.65E+08	2.60E+09	9.97E+08	1.30E+07	7.21E+08	1.42E+07	3.27E+08
CM-244	1.17E+08	1.95E+09	8.44E+08	9.09E+05	5.43E+08	2.12E+06	3.04E+08

TABLE 2-10. Pathway Dose Conversion Factor - 7

SURF-WATER

	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	2.37E+06	1.42E-01	2.37E+06	2.37E+06	2.37E+06	2.37E+06	2.37E+06
C-14	3.76E+07	1.88E+08	3.76E+07	3.76E+07	3.76E+07	3.76E+07	3.76E+07
FE-55	4.45E+06	2.31E+07	1.63E+07	8.61E+05	8.61E+05	9.45E+06	9.69E+06
CO-60	1.46E+08	1.24E+08	1.34E+08	1.24E+08	1.24E+08	1.24E+08	3.11E+08
NI-59	9.82E+06	5.20E+07	1.87E+07	1.38E+06	1.38E+06	1.38E+06	4.95E+06
NI-63	2.26E+07	6.74E+08	4.67E+07	4.28E-01	4.28E-01	2.42E+02	9.74E+06
SR-90	8.18E+09	3.33E+10	8.83E+06	8.83E+06	8.83E+06	8.83E+06	9.71E+08
NB-94	3.23E+07	3.32E+07	3.27E+07	3.19E+07	3.26E+07	3.19E+07	4.50E+09
TC-99	3.65E+05	9.09E+05	1.35E+06	2.08E+00	1.70E+07	1.15E+05	4.42E+07
I-129	4.28E+07	1.75E+07	1.56E+07	3.07E+10	2.93E+07	3.64E+06	5.53E+06
CS-135	1.44E+08	3.52E+08	3.25E+08	1.39E+00	1.23E+08	3.68E+07	7.60E+06
CS-137	1.30E+09	1.45E+09	1.98E+09	1.29E+07	6.81E+08	2.35E+08	5.09E+07
U-235	2.11E+08	3.29E+09	1.18E+07	1.18E+07	7.78E+08	2.10E+07	3.32E+08
U-238+D	1.87E+08	3.14E+09	7.74E+05	7.74E+05	7.18E+08	9.32E+06	2.26E+08
NP-237+D	2.57E+08	6.19E+09	5.44E+08	7.13E+06	1.87E+09	8.11E+06	3.63E+08
PU-238	7.49E+07	2.93E+09	4.19E+08	1.03E+06	3.17E+08	1.22E+07	3.14E+08
PU-239	8.29E+07	3.39E+09	4.63E+08	3.93E+05	3.51E+08	1.09E+07	2.86E+08
PU-241	1.43E+06	7.09E+07	3.74E+06	1.31E-01	6.60E+06	1.86E+04	6.00E+06
PU-242	8.02E+07	3.14E+09	4.46E+08	7.67E+05	3.38E+08	1.09E+07	2.81E+08
AM-241	3.72E+08	5.57E+09	1.97E+09	4.19E+06	2.77E+09	5.35E+06	5.07E+08
AM-243	3.65E+08	5.57E+09	1.91E+09	4.84E+06	2.72E+09	5.93E+06	5.94E+08
CM-243	2.09E+08	3.35E+09	1.28E+09	1.30E+07	9.26E+08	1.42E+07	4.18E+08
CM-244	1.51E+08	2.52E+09	1.09E+09	9.09E+05	7.00E+08	2.12E+06	3.93E+08

TABLE 2-11 . Pathway Dose Conversion Factor - 8

ATMOSPHERE

	TOTAL BODY	BONE	LIVER	THYROID	KIDNEY	LUNG	GI-LLI
H-3	4.45E+10	5.19E+07	4.45E+10	4.45E+10	4.45E+10	4.45E+10	4.33E+10
C-14	2.66E+11	1.33E+12	2.66E+11	2.66E+11	2.66E+11	2.66E+11	2.65E+11
FE-55	4.83E+10	2.06E+11	1.54E+11	1.61E+10	1.61E+10	2.80E+11	9.36E+10
CO-60	2.68E+12	2.34E+12	2.50E+12	2.34E+12	2.34E+12	2.63E+13	5.27E+12
NI-59	1.50E+11	7.73E+11	2.84E+11	2.58E+10	2.58E+10	5.78E+10	7.65E+10
NI-63	3.34E+11	1.00E+13	6.93E+11	1.56E+08	1.56E+08	8.82E+10	1.38E+11
SR-90	1.53E+14	6.21E+14	1.67E+11	1.67E+11	1.67E+11	1.98E+11	1.53E+13
NB-94	6.10E+11	6.12E+11	6.11E+11	6.10E+11	6.11E+11	1.33E+12	2.15E+12
TC-99	5.61E+09	1.20E+10	1.87E+10	7.60E+08	2.27E+11	8.80E+09	5.45E+11
I-129	6.91E+12	3.69E+12	3.29E+12	6.33E+15	6.10E+12	8.57E+11	1.24E+12
CS-135	5.73E+11	1.44E+12	1.33E+12	5.08E+08	5.02E+11	1.55E+11	3.00E+10
CS-137	5.36E+12	6.12E+12	8.27E+12	2.42E+11	2.97E+12	1.18E+12	3.90E+11
U-235	5.37E+12	8.52E+13	2.21E+11	2.21E+11	2.00E+13	3.36E+15	5.84E+12
U-238+D	4.79E+12	8.11E+13	1.45E+10	1.45E+10	1.85E+13	3.12E+15	4.00E+12
NP-237+D	5.24E+14	1.21E+16	1.13E+15	1.34E+11	3.87E+15	3.60E+14	5.79E+12
PU-238	2.01E+14	4.13E+15	2.81E+15	1.92E+10	8.85E+14	4.08E+15	5.30E+12
PU-239	2.25E+14	4.85E+15	3.13E+15	7.40E+09	9.66E+14	3.84E+15	4.83E+12
PU-241	3.06E+12	7.55E+13	4.57E+13	4.78E+07	1.45E+13	6.80E+12	1.01E+11
PU-242	2.17E+14	4.53E+15	3.05E+15	1.44E+10	9.65E+14	3.68E+15	4.74E+12
AM-241	5.08E+14	7.18E+15	6.66E+15	7.87E+10	3.87E+15	4.24E+14	5.43E+12
AM-243	5.00E+14	7.10E+15	6.50E+15	9.10E+10	3.79E+15	4.00E+14	6.31E+12
CM-243	3.87E+14	6.20E+15	5.62E+15	2.44E+11	1.77E+15	4.40E+14	5.87E+12
CM-244	2.82E+14	4.43E+15	4.17E+15	1.71E+10	1.29E+15	4.40E+14	5.45E+12

to humans as a better indicator of the limiting exposure due to I-129 than the thyroid dose.(30) This selection results in a significant difference in limiting exposures since the fundamental dose conversion factors for thyroid are about 1000 times that of total body (see Tables 2-4 through 2-11). A correction to the calculated I-129 thyroid PDCF's to account for dilution with natural iodine has not been made in this report, however, in view of the evidence, judicious use of the I-129 thyroid PDCF's is indicated.

2.4 Release/Transport Scenarios

The connection between the radioactive concentrations at the various biota access locations and the potential radiological dose to man was examined in the previous section. This section introduces and summarizes the remaining part of the waste-to-man connection, namely the release/transport scenarios that relate the radioactive concentrations in the waste to the radionuclide concentrations at the biota access locations. Considerable additional information regarding the release/transport scenarios is provided in Chapter 3.0.

As detailed in Section 2.3, there are seven release/transport scenarios to be considered. Three of these scenarios - the accident, construction, and agriculture scenarios - depend on the concentration of the individual waste streams, and hence are termed the "concentration scenarios". The other four - leaching and migration with well and open water access, surface water transport of exposed waste, and atmospheric transport of exposed waste - depend on the total inventory of radioactivity and the total volume of the disposed waste, and are termed the "total activity scenarios." These are examined below.

2.4.1 Concentration Scenarios

The first scenario considered concerns accidents that may happen during the operational period of the disposal facility lifespan, and which may result in off-site atmospheric transport of radionuclides. The other two scenarios are concerned with exposures to a potential inadvertant intruder. An intruder may unintentionally come across a closed waste disposal site due to a temporary breakdown in institutional controls, and subsequently modify it for a specific purpose, such as housing construction or agriculture. As a result, short- and long-term radiation exposures to the individual can ensue.

Two of the concentration scenarios (accident and inadvertant intruder-construction) are acute exposure events. That is, the release and subsequent exposure occurs for a limited period of time (less than a year). The other scenario (inadvertant intruder-agriculture), however, is assumed to be chronic, since it is possible (but unlikely) that the intruder would live for several years at the site before it is discovered that there is a hazard.

Very few individuals are involved in the concentration scenarios, and they may also be distinguished from the total activity scenarios by the dose limitation criteria which may be applied. In other words, different limits on allowable human doses may be used, depending upon whether a few individuals or populations are exposed.(2,3,13,17) The equation generally applicable to the above concentration scenarios is:

$$C_a = I \times C_w \tag{2-2}$$

where (C_a) denotes the radionuclide concentration at the biota access location and (C_w) denotes the radionuclide concentration of the waste, both in units of (Ci/m^3), and (I) is the dimensionless interaction factor, which depends on the specific scenario considered.

For these scenarios, the as-generated waste radioactive concentrations are utilized.(1) For the intruder-construction and intruder-agriculture scenarios, this is conservative since it is equivalent to the assumption that the inadvertant intruder initiates the scenario at a location containing waste from the last year of disposal facility operation.

The interaction factor (I) can generally be expressed through the following equation:

$$I = f_o \times f_d \times f_w \times f_s \tag{2-3}$$

where all the parameters are dimensionless, and where

f_o = time-delay factor;
f_d = site design and operation factor;
f_w = waste form and package factor; and
f_s = site selection factor.

The time-delay factor (f_o) is expressed as an exponential radionuclide decay factor and incorporates the effects of the closure period and the active institutional control period. The activities are decayed to the time that the specific scenario is initiated. This factor is a property of the scenario and the disposal technology being considered. For the accident scenario, no credit for radioactive decay can be assumed and (f_o) will be taken equal to one. However, for the construction and agriculture scenarios, it is given by the formula:

$$f_o = \exp[-\lambda T] \tag{2-4}$$

where λ is the radionuclide decay constant in units of year^{-1}, and T is the period between the cessation of disposal operations and the end of active institutional control period.

The site design and operation factor (f_d) expresses the waste fraction that is available to the transfer agent. It usually depends on the efficiency of the disposal design. Furthermore, its definition and value depends on whether the scenario is an inadvertant intruder scenario or an accident scenario (see Sections 3.3 and 3.7).

The waste form and package factor (f_w) expresses the resistance of the waste to mobilization by the specific transfer agent initiating the scenario. For example, this factor would be considerably less than unity for waste streams solidified in a matrix and/or packaged in containers that are likely to retain their integrity at the time of inadvertant intrusion. This factor is a property of the waste stream as it is being disposed.

The site selection factor (f_s) depends on many parameters. In some cases, it is proportional to the fraction of a year that the human exposure episode takes place. Since the dose conversion factors presented in Section 2.3 have been calculated for a full year exposure period, the factor (f_s) must compensate for this calculational convenience. In other cases, however, (f_s) is also proportional to the release/transport/transfer factor between the biota access locations. For example, for the inadvertant intruder-construction scenario, it is proportional to the transfer factor between contaminated soil and contaminated air. This factor is examined in greater detail in Appendix A.

A brief description of the concentration scenarios is presented below. Specific values of the transfer factors used to calculate impacts are discussed in Chapter 3.0 and Appendix A.

Accident Scenario

Non-occupational acute radiation exposures may result from planned and unplanned releases of material to offsite environs during the operational life of the facility. Planned releases would be addressed on a site-specific basis during the licensing phase of site startup. This report considers only the unplanned (accidental) releases. Two accidental release scenarios can be postulated. One of them involves a postulated breaking open of a waste container and subsequent release of airborne radioactivity, and the second scenario considers the consequences of a fire igniting in an open disposal trench, with subsequent burning of a portion of the waste and airborne release of combustion products. The comparative severity of these two scenarios depends on various parameters including those associated with the waste form and with site operations.

Construction Scenario

An inadvertant intruder may choose to excavate or construct a building on a disposal site. Under these circumstances, dust will be generated from the application of mechanical forces to the surface materials (soil, rock) through tools and implements (wheels, blades) that pulverize and abrade these materials. The dust particles generated are entrained by localized turbulent air currents. These suspended particles can thus become available for inhalation by the intruder. The intruder may also be exposed to direct gamma radiation resulting from airborne particulates and by working directly in the waste-soil mixture, etc. (See Section 2.3 for the uptake pathways considered.) For convenience, this scenario is called the intruder-construction scenario, and appropriate values applicable to typical construction activities are used.

Agriculture Scenario

In this scenario, an inadvertant intruder is assumed to occupy a dwelling located on the disposal facility and ingest food grown in contaminated soil. Garden crops may be subject to radionuclide contamination as a result of direct foliar deposition of fallout particulates. Garden crops may also uptake radionuclides via soil-root transfer from contaminated soil. The soil may be initially contaminated, or it may become contaminated as a result of deposition. The inadvertant intruder may also be exposed to direct ionizing radiation such as beta and gamma radiation from the naturally suspended radioactivity and from the waste-soil mixture. He may also inhale contaminated air particulates, etc. (See Section 2.3 for the uptake pathways considered.) This scenario is called the intruder-agriculture scenario.

2.4.2 Total Activity Scenarios

This section considers those release/transport scenarios that are dependent upon the entire activity disposed of at the site. Therefore, all the waste streams disposed at the site contribute to the radionuclide concentrations at the biota access locations. The degree of contribution from a given waste stream is a function of its volume and characteristics (e.g., its form and packaging) and facility design and operating practices (e.g., waste segregation).

All of the total activity scenarios are chronic exposure scenarios (i.e., continuous release and exposure). Theoretically, all four different types of biota access locations are possible as a result of the total activity scenarios. Some of the release/transport scenarios that lead to them are considered below.

The equation applicable to the total activity scenarios for each radionuclide is:

$$C_a = \sum I_i \times C_{wi} \tag{2-5}$$

where (C_a) and (C_{wi}) denote the radionuclide concentrations at the biota access location and in the $(i)^{th}$ waste stream, respectively, in units of (Ci/m^3), and (I_i) is the interaction factor between the $(i)^{th}$ waste stream and the biota access location. The capital sigma indicates that the total radionuclide concentration at the biota access location is a summation of the radioactivity contributed by each waste stream. This summation may also include any potential integration that must be performed due to the areal extent of the disposal site and the areal distribution of the waste streams.

For these scenarios, generation time-averaged radioactive concentrations averaged over the time of waste generation and disposal are utilized as a source term.(1) In other words, the radionuclides in waste streams that are disposed of at the beginning of the disposal site operational period are decayed to the end of the operational period. The need for this averaging is obvious since the entire waste volume interacts with the environment.

The interaction factor (I_i) can generally be expressed through the following equation:

$$I_i = f_o \times f_{di} \times f_{wi} \times f_{si} \tag{2-6}$$

where the subscript i denotes the waste stream, and where:

f_o = time-delay factor (dimensionless);
f_{di}= site design and operation factor (dimensionless);
f_{wi}= waste form and package factor (m^3/yr); and
f_{si}= site selection factor (yr/m^3);

and where the values of f_{di}, f_{wi} and f_{si} may be functions of the properties of the individual waste streams.

Groundwater Scenarios

There are several groundwater scenarios depending on the assumed access location. One of the access locations is an on-site well which may be drilled and used by a potential inadvertant intruder (intruder-well scenario); another is a well at the boundary of the site which may be utilized by individuals (boundary-well scenario), a third location is a well pumped for common use by a small population some distance away from the disposal facility (population-well scenario); and the fourth location is a stream that receives the discharge from the unconfined groundwater table and which may be used by a larger population (population-surface water scenario).

In this report, it is assumed that the water table gradient underneath the site is unidirectional, and that the individual-well located at the boundary of the disposal area (rather than the boundary of the site) contributes to the intruder scenarios. This location is more conservative than a well located in the middle of the site since only about half of the potential effluent from the site would contribute to the contamination at a well in the middle of the site whereas all of the potential effluent from the site would contribute to the location assumed for the intruder-well.

The factors f_{di} and f_{wi} are assumed to be independent of the areal extent of the disposal facility, however, the factor f_{si} represents these areal relationships. The factors f_{di} and f_{wi} and their computations are straightforward and representative values for these factors are given in Section 3.0. However, a brief discussion of f_{si} is presented below.

The following general equation is applicable to determine the site selection factor f_{si}:(31,32)

$$f_{si} = r_g \, r_{ti} \, / \, Q \tag{2-7}$$

where

r_g = dimensionless time independent reduction factor due to the transverse (perpendicular to the groundwater velocity direction) spatial relationship of the disposal facility with the discharge location,

r_{ti} = dimensionless reduction factor due to migration and radioactive decay; this factor is dependent on both space and time including the longitudinal (in the direction of the groundwater velocity) spatial relationship of the disposal facility with the discharge location; and

Q = dilution factor in units of volume/time.

The factor Q is independent of the characteristics of the disposed wastes and is also independent of the geometrical relationship of the disposal facility with the discharge location. The factor Q may be the pumping rate of a well or the flow rate of a river. The factors r_g and r_{ti} are discussed in Section 3.5.

Exposed Waste Scenarios

In these scenarios, part or all of the surface area of the disposed waste is assumed to be exposed through some means, and this exposed waste is assumed to be accessed by transfer agents such as wind or water. The mechanism that initiates uncovering of the waste may be erosion of the waste cover by surface water or wind action, or it may be anthropogenic activities such as construction or farming. Initiating mechanisms related to human activities are examined in the intruder-agriculture and intruder-construction scenarios, and initiating mechanisms related to erosion of the waste cover are examined in Appendix A.

There are two basic exposed waste scenarios depending on whether the transfer agent is wind or surface water. For the wind transport scenario, only population exposures are considered; individual exposures are bounded by the above intruder-construction and intruder-agriculture scenarios. The entire exposed waste area is assumed to be a point source for the impact calculations since the population is assumed to be comparatively distant.

For the surface water transport scenarios, exposures to individuals consuming water from an open water access location is considered. Again the disposal facility is considered a point source for this scenario since it is not possible to consider the areal extent of the facility for surface water transport. The equations and values for the various barrier factors used in the calculations are examined in Chapter 3.0 and Appendix A.

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3.0 DISPOSAL IMPACTS

This chapter further develops the calculational procedures utilized to determine the impact measures associated with the disposal of LLW. These impact measures include individual and population exposures, occupational exposures, costs, energy use, and land use.

Section 3.1 is an introduction to the chapter and presents a discussion on the information base and the approach utilized in the radiological disposal impacts calculations. Following this introduction, Section 3.2 presents the background assumptions regarding the disposal technology alternatives considered, discusses how these assumptions are incorporated into the impact calculations, and presents background information on the specific values utilized to quantify the effects of these alternatives. Section 3.3 presents procedures through which the effects of waste form and packaging are incorporated into the calculations, and presents background information on the specific values selected to quantify the effects of waste form and packaging on the impact calculations.

Following these three background sections, Sections 3.4 through 3.7 present the equations and specific parameter values used to calculate individual and population exposures for the scenarios considered in Chapter 2.0. Finally, Section 3.8 details the calculation of many of the other impact measures considered in this report, including occupational exposures, land-use, disposal costs, and energy use.

3.1 Introduction

The impact measures associated with the disposal of LLW are strongly dependent on waste form and package properties,(1) and disposal facility environment, design, and operating practices.(2,3) This section presents a discussion on the information base utilized in this report and the general approach adopted.

3.1.1 Information Base

The information base for disposal impact calculations includes three main components: waste characteristics, disposal facility environment, and disposal facility design. In this report, the continental U.S. is assumed to be divided into four regions, based on the 5 U.S. NRC regions (see Appendix C): the northeast (Region I), the southeast (Region II), the midwest (Region III), and the west (Regions IV and V).(1) Waste characteristics and disposal facility environment are correlated with these four regions as discussed below.

The first component of the information base is on waste characteristics. The calculational methodology allows consideration of a wide range in waste forms and processing options. In many previous studies on LLW management and disposal, the disposed waste was usually assumed to be a mostly uncharacterized mass with little attempt to distinguish, in a quantitative manner, the different waste forms. In this work, however, LLW is separated into 36 waste streams and each waste stream is characterized in terms of its physical, chemical, and radiological properties. The volumes of each waste stream are considered on a regional basis. That is, the volume of a given waste stream is projected for each of the above four regions over the next 20 years, which allows consideration of regional impacts of management and disposal of LLW. Furthermore, four generic alternative waste form and processing options are considered. These generic processing options, called "waste spectra," represent four relative levels of waste processing activities applied to the 36 waste streams characterized. The waste spectra have been developed to limit the number of waste form and packaging alternatives that would have to be analyzed, since an infinite number of possible combinations of various waste streams and processing options are available. The waste spectra considered (see Chapter 6.0) range from Waste Spectrum No.1, which characterizes a continuation of existing or past waste management practices, to Waste Spectrum No.4, which characterizes the maximum volume reduction and improved waste forms that currently can be practically achieved. The waste streams corresponding to a given spectrum may be transported to and disposed into facilities located at the regional sites and the resulting potential impacts calculated.

The second component of the information base is the disposal facility environment. In each region, a hypothetical regional disposal facility site has been characterized (see Appendix C). These sites, while not representing any particular location within the region, represent typical environmental conditions within the regions. This allows consideration in the calculational methodology of a wide range of environmental parameters such as the amount of rainfall or the average distance from the waste generator to the disposal facility site. (One of these four sites, the southeastern site, is frequently referred to in this work as the reference disposal facility site.)

The third component of the information base is the disposal facility design. To develop the calculational procedures, a reference near-surface disposal facility is assumed. A description of this disposal facility design, which is condensed from Appendix E of the U.S. NRC environmental impact statement on management and disposal of LLW,(3) is provided in Appendix C of this report. A number of alternative disposal facility designs and operating practices (e.g., thicker disposal cell covers, use of cement grout) may be considered to estimate the effect of these alternatives on the impact measures.

3.1.2 General Approach

From the above information base, it can be seen that, when considering the effect of alternative regional, waste form, and facility design characteristics on the magnitude of the impact measures calculated, an extremely large number (thousands) of possible permutations can be generated. To enable development of performance objectives and technical criteria for LLW disposal, the number of these permutations must be controlled and analyzed in a systematic manner. To do this, two features in the disposal impacts analysis have been adopted: (1) use of a reference disposal facility and a reference waste volume distribution, and (2) extensive use of computer technology including the use of waste form and disposal technology indices.

For the first feature, a reference disposal facility is assumed which is located in the humid eastern U.S. For this work, the reference disposal facility site is assumed to have environmental characteristics corresponding to the southeast regional site, although either the northeast regional site or the midwest regional site could have been used for this purpose.(3) The reference waste volume distribution is generated through summing all the waste volumes projected to be generated in each of the four regions for each of the 36 waste streams, and normalizing these volumes to one-million m^3 of waste for Waste Spectrum 1.(1) This allows the effects of alternative waste spectrum and disposal facility designs to be compared on a common basis.

For the second feature, five computer codes have been written to manipulate the alternatives and determine impact measures. These include the codes INTRUDE, GRWATER, OPTIONS, INVERSI, and INVERSW, and a description of these codes is provided in Chapter 6.0. In these codes, extensive use of "indices" have been made to characterize waste stream properties or disposal facility environmental and design alternatives (see Sections 3.2 and 3.3). In other words, the value of the indices are used to initiate specific calculational procedures or use specific values of appropriate parameters. Use of integer indices enables rapid and convenient consideration of alternatives for rulemaking. In addition, use of indices enables updates of the data base and calculational procedures to be readily accomplished without changing the values of the indices or the structure of the calculations. In the remainder of this report, the calculational procedures are developed and discussed in the context of these indices.

3.2 Disposal Technology Indices

In order to analyze the impacts from disposal of LLW, alternative disposal technology properties and their effect on the impact measure calculations must be quantified. For example, depending on specific operational procedures such as random or stacked disposal, the values of the barrier factors presented in Section 2.2 vary. In this report, the disposal technology properties have been expressed in the form of integer indices that refer to a specific procedure used in the barrier factor computations or determine a specific value of the environmental parameters. These indices, which will be referred to as the disposal technology indices, basically denote the selection options available for a specific property. These selection options may be in the form of a specific calculational procedure or a specific value for an environmental property.

The disposal technology properties that have been considered in the calculation of impacts in this report are summarized in Table 3-1, and are discussed below.

3.2.1 Region Index - IR

This index, whose value is 1 or higher, is set depending upon the region considered and determines use of a specific set of environmental properties in the impact calculations. The main effect of the region index is on the site selection factor. Environmental properties that depend on the region index are presented in Table 3-2.

The value of this index corresponding to each of the regions considered (see Appendix C) are as follows:

IR = 1 : Northeastern Region
IR = 2 : Southeastern Region
IR = 3 : Midwestern Region
IR = 4 : Western Region

TABLE 3-1 . Disposal Technology Indices

Property and Index		Description
Region	- IR	Geographic location of the disposal facility.
Design	- ID	Two options are considered: regular trenches, and the so-called "concrete walled" trenches.
Cover	- IC	Three options on the cover between the waste and the atmosphere are considered: regular, thick, and intruder barrier.
Emplacement	- IE	Three options on the emplacement of the waste are considered: random, stacked, and random combined with decontainerized disposal for unstable wastes.
Stabilization	- IX	Three options on the stabilization program applied to disposal cells, which may contain structurally unstable wastes, are considered: regular, moderate, and extensive.
Layering	- IL	Option on separating and putting selected waste streams (usually with higher external radiation levels) at the bottom of the disposal cell.
Segregation	- IS	Option to segregate and separately dispose of wastes that are combustible/compressible and those that could contain complexing agents.
Grouting	- IG	Option on filling of the interstitial spaces between the wastes with grouting material.
Hot Waste Facility	- IH	Option on having a special area within the disposal facility with special procedures to handle high activity wastes.
Closure Index	- IQ	This index indicates the activities during the closure period (regular or extensive).
Care Level Index	- ICL	This index indicates the care level anticipated during the active institutional control period (low, moderate, and high).
Post Operational Period (Years)	- IPO	Duration of the period between the cessation of active disposal and the transfer of the title from the site operator to the site owner.
Institutional Control Period (Years)	- IIC	Duration between transfer of the title to the site owner and the assumed time for loss of institutional controls over the site.

TABLE 3-2 . Region Index Dependent Properties

Symbol	Scenario	Environmental Property
TPO	Accident	Air-to-air transfer factor
FSC	Construction	Soil-to-air transfer factor
FSA	Agriculture	Soil-to-air transfer Factor
QFC	Groundwater	Dilution Factor
TTM	"	Water Travel Time
DTTM		Incremental Water Travel Time
TPC	"	Peclet Number
DTPC		Incremental Peclet Number
RGF	"	Factor r_g
RET	"	Retardation Coefficients
PRC	"	Infiltrating Percolation
POP	Exposed Waste	Air-to-air and surface water transfer factors.
DIST	Transportation	One-way travel distance
STPS	"	Number of stops per trip
CASK	"	Cask days per round-trip

In this report, the southeastern region environmental characteristics are used to represent the environmental characteristics of the reference disposal facility site. Variations of the values assumed for the regions (e.g., to perform sensitivity analyses) can also be triggered through the use of the region index.

3.2.2 Design and Operation Indices

There are four design and operation indices: design index - ID, cover index - IC, emplacement index - IE, and stabilization index - IX. The values of these indices are 1 or higher denoting the options available in the design of the disposal facility; details of the options can be found in Appendices E and F of reference 3. These indices are considered below.

The Design Index - ID characterizes the disposal cell design used for radioactive waste disposal. Two options have been used in this study: regular trench disposal and concrete-walled trench disposal. This index primarily affects the site design factor.

In this report, three different "efficiencies" are utilized to describe the specific procedures employed in the disposal of wastes:

(1) the volumetric disposal efficiency which is defined as the volume of disposal space available in the disposal cell (in m^3) per unit surface area (in m^2) of the disposal cell,

(2) the emplacement efficiency which is the volume of waste emplaced in the disposal cell (in m^3) per unit volume (in m^3) of available disposal space, and

(3) the surface efficiency which is defined as the ratio of the surface area occupied by the disposal cells to the surface area occupied by the disposal cells plus the surface area between these cells that have not been utilized for disposal.

The design index determines the volumetric disposal efficiency and the surface efficiency of the design. The emplacement efficiency is discussed below. Use of a hot waste facility (see Section 3.2.3), which is defined as a special group of disposal cells used for disposal of relatively high activity waste, is not included in the above definitions; its efficiencies are assumed to be independent of the design index.

The Cover Index - IC can be either 1, or 2, or 3, and it denotes whether a "regular" cover (denoted by 1), a "thick" cover (denoted by 2), or an "intruder barrier" cover (denoted by 3) is placed over the disposed waste. These three options are described in reference 3, and are summarized below.

A regular cover refers to a 1 meter thick cover below the existing grade plus a minimum of 1 meter cover above grade. A thick cover refers to the same 1 m thick cover below the existing grade plus a minimum of 2 meters thick engineered cover (e.g., containing low permeability layers) to minimize infiltration of precipitation. An intruder barrier cover refers to the same 1 meter thick cover below the existing grade plus a minimum of 5 meter thick engineered cover (e.g., low permeability layers, interbedded sand/gravel/boulder layers) to minimize infiltration and prevent intrusion for at least 500 years.

Successful coverage of a waste disposal cell with an "impervious" system of layers is an important engineering barrier against percolation of precipitation into the waste mass. It also increases the stability of the waste by minimizing the effects of external agents. This option affects both the site design factor and the waste form factor.

The Emplacement Index - IE denotes the specific method used to emplace the waste in the disposal cells and primarily affects the site design

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factor. The three options considered and the associated emplacement efficiencies are discussed below.

Random emplacement (index value 1) involves simply dumping the waste directly into the disposal cell. It is the fastest method which can be used, and therefore leads to the lowest occupational exposures. However, random emplacement of waste containers may be accomplished with only about 50% emplacement efficiency (one-half the available space is empty or filled with earth or other material), and there is a higher probability of the occurrence of accidents as well as container damage during haphazard dumping.

Stacked emplacement (index value 2) involves stacking waste containers in neat piles, using cranes, fork lifts, etc. This technique may be difficult to employ on a routine basis but represents the maximum practical volume utilization. In this case, the potential for accidents and waste container damage is much lower, and approximately 75% of the available disposal space is used - i.e., the emplacement efficiency is 0.75. However, additional fuel must be used to operate the heavy equipment used for emplacement, and occupational exposures increase as more men must spend more time near the disposed waste.

Decontainerized emplacement (index value 3) involves randomly disposing of all structurally stable wastes, and decontainerizing and disposing those low-activity wastes that are, over the long-term, structurally unstable. In this case, the disposal facility would be operated somewhat like a sanitary landfill. This option can substantially reduce disposal cell instability problems by accelerating the compression of unstable wastes. However, it requires a significantly increased effort by the site operator and leads to higher occupational exposures.(3) The emplacement efficiency of this option is estimated to be about

0.5 since part of the waste containers are randomly emplaced, and additional material such as soil or sand between wastes is likely to be required during emplacement of decontainerized wastes.

The Stabilization Index - IX, whose value can be either 1, 2, or 3, denotes the extent to which the disposal cells are stabilized. Such stabilization measures may be implemented during disposal operations and/or during closure after the cessation of disposal operations. Past disposal experience(4) indicates that the difficulties currently experienced at several existing disposal sites may have resulted from the natural compaction and decomposition of the wastes leading to subsidence of the disposal cell cover and increased rainwater percolation.

A stabilization program with no special compaction procedures other than the use of the weight of heavy equipment is denoted by 1. A more extensive stabilization program involving sheeps-foot rollers and/or vibratory compaction during operations is denoted by 2. A program involving very extensive techniques such as dynamic compaction or similar measures is denoted by 3. This option affects the site design factor and the waste form and package factor.

3.2.3 Site Operational Options

Four operational options which may be exercized in the design of the disposal facility are considered: layering - IL, segregation - IS, grouting - IG, and use of a hot waste facility - IH. The values of all these indices are either 0, signifying that the option has not been exercized, or 1, signifying that the option has been implemented in the design. These options are briefly discussed below.

Layering Option - IL denotes whether selected waste streams (usually those with higher external radiation levels) are separated and disposed of at the bottom of the disposal cells. This practice is frequently implemented at the existing sites to minimize occupational exposures. This option, however, affects the site design factor significantly by limiting access of potential inadvertant intruders to the layered waste streams.

Segregation Option - IS indicates whether, during the disposal operations, the wastes are segregated and disposed of in separate disposal cells based on their compressibility/combustibility and whether they contain radionuclide-complexing chemical agents. Implementing the segregation option increases the performance capability of the disposal cell covers by limiting expected long-term waste volume reduction after disposal to those cells containing unstable wastes. It also limits the effects of chemicals that may increase radionuclide mobility to those cells containing these chemicals. This index primarily affects the groundwater scenario through the site design factor and the waste form factor.

Grouting Option - IG indicates whether the interstitial spaces between the waste packages are filled with a material that will improve disposal cell stability. During the grouting operation, as each layer of waste is emplaced in the disposal cell, pumpable concrete (grout) is pumped in to fill all interstitial spaces between the waste containers. Some grout is also placed under the lowest layer of waste and on top of the total waste mass. Grouting is expensive, but its use is advantageous in that the waste is totally encapsulated and immobilized. There is little opportunity for infiltrating precipitation to contact the waste, the grout provides stability, and potential long-term migrational and intruder impacts are minimized. This option affects the site design factor and the waste form factor.

Hot Waste Facility Option - IH indicates use of specially designed disposal cells utilizing special operational procedures to dispose of certain high activity waste streams. In this report, if a hot waste facility is used, it is located at the center of the disposal facility. Confinement of the wastes and limiting their interaction with transport agents such as wind and water are the primary considerations in hot waste facility design; other factors such as costs and surface efficiency are secondary design objectives. Consequently, the hot waste facility represents an "idealized" confinement concept which is nonetheless achievable utilizing existing disposal technology. If the hot waste facility option has been included in the site design, each waste stream is tested for acceptability at the hot waste facility if it fails an acceptability test for other and more conventional near-surface disposal cells (see Section 3.4). Various example "hot waste facility designs" such as use of caissons and concrete walled trenches are considered in Appendix F of reference 3. In this report, the hot waste facility is assumed to be composed of concrete walled trenches.

3.2.4 Post Operational Indices

There are four post operational indices: closure index - IQ, care level index - ICL, post operational period - IPO, and active institutional control period - IIC. These are considered below.

The Closure Index - IQ, whose value can be 1 or 2, refers to actions implemented during the closure period after the cessation of disposal operations and prior to the transfer of the site title to the site owner.

An index value of 1 indicates that closure operations are assumed to last two years and involve a relatively modest level of effort by the facility operator. Closure operations are assumed to consist of dismantlement and decontamination of site buildings (except those necessary for the site owners during the active institutional control period), disposal of wastes generated during the dismantlement and decontamination operations, final contouring (including implementation of final surface drainage systems) and vegetation of the site, final radiation surveys, etc.

An index value of 2 indicates that a complete site restabilization program is carried out at site closure in addition to the other closure operations discussed above. This closure program, which is assumed to increase the closure period to four years, is intended to enhance the integrity of the disposal cell covers and therefore reduce the amount of water potentially infiltrating into the disposal cells. The restabilization program involves: (1) stripping off the existing disposal cell covers, (2) use of vibratory compaction or similar measures to accelerate disposal cell compression, (3) backfilling the resultant compressed areas, (4) reconstruction of the cell covers, and (5) revegetation of the covers. Implementation of these closure measures is assumed to be equivalent to the implementation of a stabilization program during disposal operations corresponding to an IX value of 2.

The Care Level Index - ICL, whose value can be either 1, 2, or 3, refers to activities during the active institutional control period that are implemented by the site owner. Different measures may have to be implemented depending on operational parameters such as the use of a particular stabilization program, whether the segregation option has been implemented, the type of disposal cell covers utilized, etc.

The level of care may range from routine surveillance and maintenance of the disposal facility (e.g., cutting the grass) which would not include any active maintenance such as cover engineering (low care level denoted by 1) to extensive stabilization and remedial programs similar to those being implemented at the Maxey Flats disposal facility (high care level denoted by 3). These care levels primarily affect the costs of the disposal facility. They are discussed briefly in Section 3.8 and more extensively in Appendix Q of reference 3.

The Post Operational Period - IPO is a property of the disposal technology utilized, and denotes the number of years between the cessation of active disposal of waste and transfer of the site title to the site owner. It includes the closure period and any observation period implemented by the site operator, and it affects the time-delay factor.

At a minimum, it would be equal to the two years required for the actions by the site operator to close the site prior to the transfer of the site title to the site owner. At a maximum, it may include four to possibly thirty years which may be required for site closure plus verification that the site condition is suitable for the transfer of the site title to the site owner.

The Active Institutional Control Period - IIC is also a property of the disposal technology, and it indicates the number of years between the transfer of the site title to the site owner and the assumed loss of active institutional controls. This period also affects the time-delay factor.

3.3 Waste Form Behavior Indices

This section presents the manner in which waste form and packaging properties are handled in the impact calculational procedures. The waste form properties are considered in the impact calculations in a manner similar to the disposal technology properties. They have been expressed through discrete indices, which are called the waste form behavior indices, that indicate a certain property of the waste form or a specific calculational procedure to be utilized in the impact calculations. The indices utilized in this report are summarized in Table 3-3.

It has been common practice in the past to give partial or no credit to the waste form properties in the calculation of impacts.(5,6) Some credit was sometimes given to the comparative leachability of the solidification agent utilized and this effect was considered in groundwater impact calculations. However, a quantitative analysis of

TABLE 3-3 . Waste Form Behavior Indices

Parameter and Symbol		Indices
Flammability	(I4)	0 = non-flammable 1 = low flammability (mixture of material with indices of 0 and 2) 2 = burns if heat supplied (does not support burning) 3 = flammable (supports burning)
Dispersibility	(I5)	0 = near zero 1 = slight to moderate 2 = moderate 3 = severe
Leachability(a)	(I6)	1 = unsolidified waste form 2 = solidification scenario A 3 = solidification scenario B 4 = solidification scenario C
Chemical Content	(I7)	0 = no chelating chemicals 1 = chelating chemicals are likely to be present in the waste form
Stability	(I8)	0 = structurally unstable waste form 1 = structurally stable waste form
Accessibility	(I9)	1 = readily accessible 2 = moderately accessible 3 = accessible with difficulty

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(a) Solidification scenario A is assumed to be 50% cement and 50% urea-formaldehyde; solidification scenario B is assumed to be 50% cement and 50% synthetic polymer; and solidification scenario C is assumed to be 100% synthetic polymer.

the mechanical strength, thermal properties, resistance to chemical and biological attack, resistance to leaching, and other properties of the waste form and their effects on all the pathways considered has not been performed.

The primary reason for this past conservatism has been the lack of detailed data on the different types of wastes included in the impact analyses. All the LWR wastes or all the non-fuel cycle wastes, or both, were considered as one stream. A contributing reason for this conservatism has been the lack of data on the performance of the waste form over long periods of time. However, in this report, the waste has been separated into 36 individual waste streams and each stream is considered separately in the impact calculations. Consequently, wide variations in waste stream properties may be quantified based on the available qualitative and comparative data on the properties of each of these waste streams. Therefore, an attempt has been made in this report to quantify the waste form properties and their effects on the impact calculations.

As shown in Table 3-3, six indices have been assigned to each waste stream for each waste spectrum considered: a flammability index, denoted by I4, a dispersibility index, denoted by I5; a leachability index, denoted by I6; a chemical content index, denoted by I7; a stability index, denoted by I8; and an accessibility index, denoted by I9. The waste streams considered in this work are summarized in Table 3-4, and the integer values for these six indices that have been assigned to each waste stream for the four waste spectra considered are given in Table 3-5.

In addition to these six indices, two more indices for each waste stream are utilized in the impact calculations: the waste processing index - denoted by I10 - is explained in Chapter 5.0, and the "disposal status index" - denoted by I11 - is calculated during the impacts analyses and is explained in Section 3.4.

TABLE 3-4 . Waste Groups and Streams

Waste Stream	Symbol
Group I : LWR Process Wastes	
PWR Ion Exchange Resins	P-IXRESIN
PWR Concentrated Liquids	P-CONCLIQ
PWR Filter Sludges	P-FSLUDGE
PWR Filter Cartridges	P-FCARTRG
BWR Ion Exchange Resins	B-IXRESIN
BWR Concentrated Liquids	B-CONCLIQ
BWR Filter Sludges	B-FSLUDGE
Group II : Trash	
PWR Compactible Trash	P-COTRASH
PWR Noncompactible Trash	P-NCTRASH
BWR Compactible Trash	B-COTRASH
BWR Noncompactible Trash	B-NCTRASH
Fuel Fabrication Compactible Trash	F-COTRASH
Fuel Fabrication Noncompactible Trash	F-NCTRASH
Institutional Trash (large facilities)	I-COTRASH
Institutional Trash (small facilities)	I+COTRASH
Industrial SS Trash (large facilities)*	N-SSTRASH
Industrial SS Trash (small facilities)*	N+SSTRASH
Industrial Low Trash (large facilities)	N-LOTRASH
Industrial Low Trash (small facilities)	N+LOTRASH
Group III : Low Specific Activity Wastes	
Fuel Fabrication Process Wastes	F-PROCESS
UF_6 Process Wastes	U-PROCESS
Institutional LSV Waste (large facilities)*	I-LIQSCVL
Institutional LSV Waste (small facilities)*	I+LIQSCVL
Institutional Liquid Waste (large facilities)	I-ABSLIQD
Institutional Liquid Waste (small facilities)	I+ABSLIQD
Institutional Biowaste (large facilities)	I-BIOWAST
Institutional Biowaste (small facilities)	I+BIOWAST
Industrial SS Waste*	N-SSWASTE
Industrial Low Activity Waste	N-LOWASTE
Group IV : Special Wastes	
LWR Nonfuel Reactor Components	L-NFRCOMP
LWR Decontamination Resins	L-DECONRS
Waste from Isotope Production Facilities	N-ISOPROD
Tritium Production Waste	N-TRITIUM
Accelerator Targets	N-TARGETS
Sealed Sources	N-SOURCES
High Activity Waste	N-HIGHACT

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* SS : Source and Special Nuclear Material; LSV : Liquid Scintillation Vials.

TABLE 3-5 . Waste Form Behavior Index Values

	Waste Spectrum 1						Waste Spectrum 2						Waste Spectrum 3						Waste Spectrum 4					
	I4	I5	I6	I7	I8	I9	I4	I5	I6	I7	I8	I9	I4	I5	I6	I7	I8	I9	I4	I5	I6	I7	I8	I9
P-IXRESIN	2	1	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-CONCLIQ	1	1	2	0	1	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-FSLUDGE	1	3	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-FCARTRG	2	2	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	2	0	4	0	1	1
B-IXRESIN	2	1	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
B-CONCLIQ	1	1	2	0	1	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
B-FSLUDGE	1	3	1	0	0	1	1	1	3	0	1	1	2	0	4	0	1	1	1	0	4	0	1	1
P-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
P-NCTRASH	0	0	1	0	0	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
B-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
B-NCTRASH	0	0	1	0	0	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
F-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
F-NCTRASH	0	0	1	0	0	2	0	0	1	0	0	2	0	0	1	0	0	2	0	0	1	0	0	2
I-COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
I+COTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N-SSTRASH	2	2	1	0	0	1	2	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N+SSTRASH	2	2	1	0	0	1	2	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N-LOTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
N+LOTRASH	3	2	1	0	0	1	3	2	1	0	0	1	1	0	4	0	1	1	1	0	4	0	1	1
F-PROCESS	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1
U-PROCESS	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1
I-LIQSCVL	3	3	1	1	0	1	3	3	1	1	1	1	1	0	4	0	1	1	1	0	4	0	1	1
I+LIQSCVL	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	0	1
I-ABSLIQD	3	3	1	1	1	1	3	1	3	1	1	1	1	0	4	0	1	1	1	0	4	0	1	1
I+ABSLIQD	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1
I-BIOWAST	2	3	1	1	0	1	2	3	1	1	0	1	1	0	4	0	1	1	1	0	4	0	1	1
I+BIOWAST	2	3	1	1	0	1	2	3	1	1	0	1	2	3	1	1	0	1	2	3	1	1	0	1
N-SSWASTE	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1	0	3	1	0	1	1
N-LOWASTE	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	0	1	3	3	1	1	0	1
L-NFRCOMP	0	0	1	0	0	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
L-DECONRS	2	0	4	1	1	1	2	0	4	1	1	1	1	0	4	0	1	1	1	0	4	0	1	1
N-ISOPROD	1	1	3	1	0	1	1	0	4	1	1	1	1	0	4	1	1	1	1	0	4	1	1	1
N-HIGHACT	0	0	1	0	0	3	0	0	1	0	1	3	0	0	1	0	1	3	0	0	1	0	1	3
N-TRITIUM	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1	3	3	1	1	1	1
N-SOURCES	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2	0	0	1	0	1	2
N-TARGETS	0	0	1	0	1	1	0	0	1	0	1	1	0	0	1	0	1	1	0	0	1	0	1	1

This section discusses the procedures through which these indices are incorporated into the analysis. Specific values assigned to the waste form properties which are denoted by the waste form behavior indices are discussed in Appendix D of reference 1. Below is a summary of the information presented in that reference.

3.3.1 Flammability Index (I4)

This index ranks waste forms according to their flammability. Waste forms which will not burn even on prolonged exposure to open flame and moderately intense heat are assigned an index of (0). These consist of waste forms that experience no evidence of combustion or decomposition upon exposure to 1000°F for 10 minutes. Those waste forms that will sustain combustion are assigned an index of (3). These include waste forms such as liquids with flame points around 600°F. Between these extremes are two additional flammability categories. Waste forms which show evidence of combustion and/or decomposition upon exposure to 1000°F for 10 minutes but will not sustain burning when the heat source is removed are assigned an index of (2). Waste forms consisting of a mixture of materials with flammability indices (0) and (2) are assigned an index of (1).(1)

The only scenario in which this index is utilized is the accident-fire scenario. Each waste stream is subjected to the accident scenarios separately. The accident-fire scenario is assumed to be possible only if (1) the waste stream being tested can support combustion (i.e., I4=3), or (2) the waste stream being tested is mixed during disposal with other waste streams containing combustible material. This latter case is possible only if there is no waste segregation (i.e., IS=0).

In the accident-fire scenario, the total volume of waste subjected to the fire is assumed to be 100 m^3 (about 250 55-gallon drums or equivalent volume). This volume is estimated from an assumed volume of 200 m^3 of waste received daily at the disposal site (which corresponds to about 1,000,000 m^3 of waste over 20 years). Two disposal cells are assumed to be simultaneously in operation, and the waste in one of the disposal cells is subjected to the accidental fire scenario.

In another study, the fraction of waste released into the atmosphere as the result of an accidental fire involving LLW has been estimated to be about 10^{-2} for combustible material, and about 10^{-5} for unsolidified resins;(7) it was estimated in this study that most of the radioactivity will remain in the ashes which remain localized. In a more recent report, it has been estimated that the fraction of combustible material released from an accidental fire involving LLW is about 10^{-3}.(8)

In this report, all unprocessed fuel cycle compactible trash, most of the institutional streams, industrial low specific activity waste, and industrial tritium waste have been assumed to be combustible (see Table 3-4), and have been assigned a flammability index of 3. Similarly, unprocessed LWR resins and cartridge filters, some of the industrial trash, and wastes solidified in a synthetic polymer (solidification scenario C) have been assigned a flammability index of 2. LWR concentrated liquids and filter sludge have been assigned an index of 1. Non-combustible trash, process waste from fuel fabrication and UF_6 conversion plants, and high specific activity industrial waste streams (see Table 3-4) have been assigned an index of 0.

In this report, waste streams with indices of 3 and 0 have been assumed to release a fraction of 0.1 and 1.25 x 10^{-5} of their activity into the air, respectively, upon being subjected to the accident-fire scenario. The waste streams with flammability indices between these two extremes have been assigned a release fraction calculated from the geometric mid-points of these two values (each index value is 20 times the adjacent lower index value). The following table gives the assumed fraction of waste released for the respective indices.

I4	f_r
0	0.0000125
1	0.00025
2	0.005
3	0.1

In other words, f_r can be expressed by the mathematical relationship $0.1x20^{(I4-3)}$. These assumptions are extremely conservative. The release fraction for combustible material is assumed to a factor of 10 to 100 higher than in other studies.(7,8) The assumed fraction for non-combustible material (I4 = 0) is slightly greater than the value previously quoted for unsolidified resins.(7)

3.3.2 Dispersibility Index (I5)

This index is a measure of the potential for suspension of radioactivity should the waste form be exposed to wind or mechanical abrasion after a significant period (on the order of 100 years). That is, this index is a measure of the degree to which individual waste streams may be suspended as respirable particles into the air by wind or the actions of a potential inadvertant intruder. Waste forms which are assumed to have a low probability of becoming suspended into respirable particles are assigned an index of (0). Those waste forms which are assumed to have a high potential of becoming suspended are assigned an index of (3). Waste forms which tend to crumble or fracture extensively and those forms that are subject to relatively rapid (within about 100 years) decomposition are assigned an index of (2). Waste forms consisting of a mixture of materials with dispersibility indices of (0) and (2) are assigned an index of (1).

The dispersibility of the waste form is dependent on the resistance of the waste form to chemical and biological attack.(1) Another property of the waste form that can be used to estimate the comparative values of this property is the compressive strengths of the waste forms.(1)

As a upper bound for this property, the most dispersible waste form (I5 = 3) has been assumed to be equivalent to soil and no credit has been considered due to waste form. This value is believed to be conservative considering that the fraction dispersible into respirable particles of powder PuO_2 packages in transportation accidents have been assumed in the past to be 0.001.(9) In the radiological impact analyses, unsolidified LWR filter sludges, all fuel-cycle process waste other than LWR process waste, all non-trash low activity wastes from industrial sources, and all non-trash institutional wastes have been assumed to be readily dispersible into respirable particles after a long time and have been assigned a dispersibility index of 3.

In comparison, waste forms such as trash are taken to be not as readily dispersible into respirable particles as waste streams such as filter sludges. These wastes easily decompose. However, the decomposed residues are likely to contain water and other liquid decomposition products which will cause the residues to aggregate into a less dispersible state. Similarly, unsolidified LWR resins would appear to be less dispersible into respirable particles than LWR filter sludge. These waste forms have been assigned a dispersibility index of 2 and the dispersible fraction is assumed to be 0.1.

Waste streams solidified in accordance with solidification scenario A and B procedures may be represented by cement properties. Cement is an inert material, and wastes solidified in cement are likely to retain their form over very long periods of time as long as no mechanical forces are applied   Similarly, wastes subjected to solidification scenario C, which may be represented by the properties of vinyl-ester styrene (VES) solidifed waste, are also likely to resist biological and chemical attack.(1) Compressive strengths of most cement waste forms are of the order of 100 psi and compressive strengths of VES solidified waste forms range from 1700 to 7000 psi. The compressive strengths of unsolidified wastes forms are of course negligible.(1)

Based on this information, wastes solidified using solidification scenario A or B procedures have been assigned an index of 1 and are assumed to have a fraction of 10^{-2} of the waste volume dispersible into respirable particles. Waste streams solidified using solidification scenario C procedures have been assumed to result in a near zero dispersible state, have been assigned an index of 0, and are assumed to have a fraction of 10^{-3} of the waste in a dispersible form.

To summarize, the fraction of the respirable dust loading in air that is contributed by each waste stream as a result of intruder activities or wind action are assumed to be the following:

I5	f_r
3	1
2	.1
1	.01
0	.001

In other words, the factor f_r is given by the relationship $10^{(I5-3)}$. The dispersibility index is applied to the intruder-construction, intruder-agriculture, and exposed waste wind transport scenarios.

3.3.3 Leachability Index (I6)

This index is a measure of a waste form's resistance to leaching and is primarily determined by the solidification procedures used. Unsolidified waste forms, which are assumed to be readily leached, are assigned an index of 1. Waste streams solidified according to solidification scenarios A, B, and C are assigned indices of 2, 3, and 4, respectively.

The solidification scenarios represent varying levels of performance that can be achieved through available solidification techniques. In this report, a level of performance designated by solidification scenario A has been simulated by assuming that half of the waste is solidified using urea-formaldehyde and the other half using cement; a level of performance designated by solidification scenario B has been simulated by assuming that half of the waste is solidified using cement and the other half using synthetic organic polymers (assumed to be equivalent to vinyl ester styrene); and a level of performance designated by solidification scenario C has been simulated by assuming that all of the waste is solidified using synthetic organic polymers.

The primary purpose of this index is to assign values to the estimated leachability potential of solidified waste streams in comparison with unsolidified waste streams. Radionuclide-specific leaching fractions for unsolidified waste streams have been estimated based upon actual leaching data from two existing disposal facilities and are presented and discussed in Section 3.5.1. The leachability index assigns values to a multiplier of these unsolidified waste stream leaching fractions. The product of the multiplier and the unsolidified waste leaching fractions gives, for each waste stream, the actual leaching fraction used in the radiological impact calculations. The multiplier is assigned a value of unity for unsolidified waste streams such as dewatered resins or trash and a value less than unity for solidified waste streams. The multiplier value assigned to solidified waste streams is dependent upon the particular solidification scenario and agent considered.

Although a large amount of experimental data is available on the leaching characteristics of various solidified waste forms, lack of widely used standardized testing procedures make quantitative comparisons difficult. Some comparisons can be made using the data presented in Reference 1. Table 3-6 is obtained from reference 1 and gives the leachabilities for various waste-binder combinations relative to that of unsolidified wastes. Experimental data was used for leaching of unsolidified resins; in all other cases complete leaching of the unsolidified wastes is assumed.

TABLE 3-6

Leachability Relative to Unsolidified Waste[a]

Waste Type	Cement	Urea-Formaldehyde	Vinyl Ester Styrene
Resins	5	0.70	2.5×10^{-4}
Concentrated Liquids			
BWR's	0.5	0.83	0.07
PWR's	0.02	0.9	0.04
Diatomaceous Earth	0.70	0.4	0.06

(a) Averaged over all radionuclides reported.

Source : Reference 1.

Calculating the geometric means of the relative leachabilities given in Table 3-6 allows an estimate of the values to be assigned to the leaching indices. Solidification scenario A is applied only to LWR concentrated liquids, the geometric mean of the four applicable values from Table 3-6 (0.5, 0.02, 0.83, and 0.9) is 0.29. Solidification scenario B may be applied to all the streams; the geometric mean of the eight applicable values from Table 3-6 (5, 0.5, 0.02, 0.7, 2.5×10^{-4}, 0.07, 0.04, and 0.06) is 0.079. Finally, solidification scenario C may also be applied to all the streams; the geometric mean of the four applicable values from Table 3-6 (2.5×10^{-4}, 0.07, 0.04, and 0.06) is 0.014. These values are approximated by assigning simple fractions to the leachability index as shown below:

I6	Multiplier
1	1
2	1/4
3	1/16
4	1/64

These values are applied primarily to the groundwater scenarios. Another scenario which may also be affected is the food (soil) uptake pathway of the intruder-agriculture scenario since the level of contamination in interstitial soil water available to vegetation may depend on the leachability of the waste. The use of the leachability index in the intruder-agriculture and groundwater scenarios is discussed in Sections 3.4 and 3.5, repectively. The values assigned to the index, I6, however, may be modified further depending on properties of the waste and the disposal technology implemented (see below).

3.3.4 Chemical Content Index (I7)

This index denotes whether a waste stream may contain chelating or organic chemicals that may increase the mobility of radionuclides during and/or after leaching. An index value of 0 indicates the likelihood that these agents are absent in the stream, whereas an index value of 1 indicates that the stream is likely to contain chelating or organic chemicals.

This index, in conjunction with the segregation option index IS (see Section 3.2.3) is used to modify the multiplier values assigned to the leachability indices for the groundwater and intruder-agriculture scenarios. The following table is used in determining the fraction leached from a particular waste form:

	Mult(I6,I7,IS)	
I6	IS=1 and I7=0	IS=0 or I7=1
1	1	1
2	1/4	1
3	1/16	1/4
4	1/64	1/16

This table should be interpreted as follows. For a waste stream with a given leachability index (I6), if the waste stream either contains chelating agents (I7=1) or is disposed mixed with other waste streams containing chelating agents (IS=0), then the higher leach fraction multiplier is used. If the waste stream does not contain chelating agents (I7=0) and it is not mixed with other wastes containing chelating agents (IS=1), then the lower leach fraction multiplier is used.

A similar procedure is applied to the soil retardation coefficients assigned to individual radionuclides. Retardation coefficients denote the potential of the disposal facility site soils to retard the radionuclides during groundwater migration. If there is no waste segregation at the disposal facility, then the retardation potential of the disposal site soils is assumed to be reduced as discussed in Section 3.5.

3.3.5 Stability Index (I8)

This index denotes whether the waste form is likely to reduce in volume after disposal due to compressibility, large internal void volume, and/or chemical and biological attack (no credit is taken for the waste containers). An index value of 0 indicates a likelihood of structural instability, whereas a value of 1 indicates a structurally stable waste form.

The stability indices presented in Table 3-5 have been assigned based on the physical descriptions of the waste provided in reference 1. In general, this index has been assigned based on the void volume and/or compressibility of the waste and its biodegradability. For example, all trash waste streams are assumed to be unstable unless they are incinerated and/or solidified. All waste forms expected to be packaged in trash or similar degradable void fillers, such as LWR noncompactible trash streams, are also assumed to be unstable.

The use of this index in the impact calculations depends on the stabilization index IX. If IX is 3 (extensive stabilization measures are implemented), then the index I8 is ignored in the calculations. If IX is 1 or 2 (regular or moderate stabilization measures), then the segregation index IS also affects the calculational procedure. If IS = 1 (segregation), then the higher percolation estimate is adopted for wastes that are unstable (I8 = 0), and the lower percolation estimate is adopted for wastes that are stable (I8 = 1); if IS = 0 (no segregation), then the higher percolation figure is adopted for all the streams (see Section 3.5).

Similarly, in the disposal cost calculations, if there is segregation, then any moderate or extensive stabilization measures (IX=2 or IX=3) are applied to only the disposal cells that contain unstable wastes; otherwise, the entire site undergoes these stabilization measures.

3.3.6 Accessibility Index (I9)

This index triggers the use of a correction factor for those unsolidified waste streams that have a comparatively high metal content. The radionuclides contained in these waste streams are not as easily accessible to transfer agents such as wind and water as are the radionuclides contained in other waste streams.

Most of the waste streams contain surface contaminated wastes and waste containing radioactivity in readily soluble forms; these streams are assigned an accessibility index of 1. The waste streams that are almost exclusively activated metals with imbedded radioactivity not readily accessible to the elements are assigned an index of 3. Only the industrial high activity waste stream (N-HIGHACT) has been assigned an index of 3. Several other streams containing a significant portion of metallic waste which have both activated and surface crud contamination have been assigned an accessibility index of 2. The waste streams assigned an accessibility index of 2 include noncompactible trash from LWR's (P-NCTRASH, B-NCTRASH) and fuel fabrication facilities (F-NCTRASH), LWR non-fuel reactor core components (L-NFRCOMP), and industrial sources (N-SOURCES). All other waste streams have been assigned an accessibility index value of 1. The value of this index does not change depending on the waste spectrum considered.

This index is applied to all the release/transport scenarios that involve wind or water transfer agents, and to all the direct radiation scenarios. In the calculations, the degree to which a waste form resists mobilization by external transfer agents is expressed through the waste form and package factor (f_w). One of the mathematical terms in the waste form and package factor is a fractional multiplier that expresses the effect of the accessibility index. This fractional multiplier is assumed to be given by the relationship $10^{(1-I9)}$; that is:

I9	Multiplier
1	1
2	.1
3	.01

A brief comparative discussion of the materials for which the accessibility index is different than unity is given below.

The main purpose of the accessibility index is to evaluate the comparative isolation from transport agents of the radioactivity contained in certain unsolidified wastes. The function of this index is similar to that of the leachability index applied to solidified wastes. The reduction of the accessibility of some radioactive materials is the result of the combined physical and chemical characteristics of these materials. No reduction is considered for wastes which contain radioactivity in forms which are readily soluble and/or displaced. Combustible trash and absorbed liquids are examples of these types of wastes.

At the other extreme are unsolidified waste streams such as activated metals where in the absence of surface contamination, much less radioactivity is initially accessible to transport agents. Industrial high activity metals are assumed to be the only waste stream of this type which is virtually free of surface contamination. Many of these activated metals are high-alloy materials (alloys with a high non-ferrous metallic component), which are inert and corrode very slowly in the disposal environment. For example, a corrosion rate of 0.002 mg/100 cm^2/day (7.3x10^{-6} g/cm^2/yr) has been quoted for high-alloy stainless steel.(10) Such corrosion produces finely-divided but highly insoluble oxides.

Although insoluble, these oxides may be more accessible by virtue of being finely divided. The percentage of the total activity of such waste forms converted to the oxide form in a given time is highly dependent on the geometry of the waste (i.e., surface area to mass ratio). For example, consider a high-alloy rod 100 cm long and 1 cm in diameter and having a density of 7.8 g/cm^3, and a pipe having the same external dimensions and density but with a wall thickness of 0.1 cm. The surface area to mass ratios are 0.259 cm^2/g for the rod and 2.56 cm^2/g for the pipe. Assuming that the activation products are distributed uniformly through both pieces, the fraction of the activity lost from the pipe is nearly ten times that of the rod (1.87×10^{-5} per year versus 1.89×10^{-6} per year). The small magnitude of both numbers clearly show the inaccessibility of the radioactivity in both cases -- especially in view of the insolubility of the corrosion products. In 1000 years, only about 0.2 percent of the activity from the rod becomes available. Based on this estimate, a conservative correction factor (multiplier) of 0.01 has been applied to these wastes in scenarios that involve dispersibility of the wastes.

The remaining unsolidified wastes fall between these two extremes. Wastes in this group include the non-compactible trash streams and non-fuel reactor core components. The trash streams include large amounts of surface contaminated failed equipment. Many pieces of equipment are internally rather than externaly contaminated and are sealed to prevent release of any free liquids they may contain (e.g., pumps). A pump sealed with 1 cm thick carbon steel caps (corrosion rate of 0.03 cm/yr)$^{(7)}$ would isolate the radioactivity for about 30 years. After this period the release of radioactivity is controlled by the activity and amount of liquid inside the piece, the nature of the internal contamination, and the ease with which the transport agents can get in and out of the equipment.

Non-fuel core components are a special case. These components are generally highly activated stainless steel pieces coated with crud deposits. The accessibility of the radioactivity of these wastes depends on the thickness of the crud layer and the relative activity of the crud and underlying metal. Crud mainly consists of oxides of iron and has been found to range in thickness from 0.0003 to 6 mil on fuel rods.(11) The strong decontamination agents necessary to remove such crud deposits from LWR primary cooling systems attests to the inaccessibility of the radioactivity they contain. Furthermore, the transporting medium must penetrate the crud layer to begin corroding the activated metal beneath. Because the fractions of activity contained in the crud and the metal components of these wastes are not well-characterized, these wastes are considered to more closely resemble non-compactible trash rather than clean-surfaced high activity metals.

A reduction factor for the direct radiation exposure components of the scenarios is also applicable due to the high metal content of the streams with an accessibility index greater than 1. This reduction is due to the self-shielding afforded by the higher density metals and packaging practices. For example, the uncollided gamma flux from a half-space source at the surface is inversely proportional to the density of the material; this effect alone would result in a gamma flux attenuation by a factor of about 7 (see Appendix A). Furthermore, when these non-compactible metallic wastes, which usually have irregular shapes, are packaged, other materials such as trash or soil that usually have much lower activities are placed around them to fill the voids. For the high energy gamma rays found in LLW (Co-60, Cs-137, and Nb-94), it takes only about 2 inches of metal shielding to result in an attenuation of 10. In this report, in view of the above two effects, a reduction factor of 10 has been applied to direct radiation exposure pathways for streams having an accessibility index greater than 1.

3.4 Waste Classification

As discussed in Chapter 1.0, a waste classification methodology is one of the essential tools to assure that uniform and environmentally acceptable practices are adopted throughout an extremely diverse industry that generates LLW. This section presents a waste classification procedure and associated tests.

An introduction to the section outlining the considerations in the approach adopted is presented in Section 3.4.1. This is followed by two sections on the intruder-construction and the intruder-agriculture scenarios that constitute the basis of the waste classification testing procedure. Finally, the waste classification testing procedure is summarized in Section 3.4.4.

3.4.1 Introduction

As discussed in Section 2.4, potential long-term exposure scenarios from LLW disposal can be seperated into two types: concentration scenarios and total activity scenarios. The concentration scenarios include those involving direct human contact with the disposed waste, such as those involving exposures to a potential inadvertent intruder. In these scenarios, potential exposures are calculated considering only the radionuclide concentrations in the waste streams assumed to be actually contacted by the intruder. The radionuclide concentrations in parts of the disposal facility not contacted by the potential inadvertent intruder do not enter into the calculations. On the other hand, exposures from the total activity scenarios are determined by considering the total radionuclide activity disposed at the facility. Examples of total activity scenarios include groundwater migration scenarios.

The fact that impacts from scenarios involving direct human intrusion into disposed waste are governed by the concentrations in the particular waste streams assumed to be contacted makes the intruder scenarios very useful for waste classification purposes. Assuming that a limit is placed on the exposures allowed to a potential human intruder, then the maximum allowable concentrations of radionuclides in waste streams to meet this exposure limit may be calculated.

Once concentration limits are determined, waste generators can relatively easily determine what class their waste belongs to by comparing the radionuclide concentrations in their wastes with the limiting concentrations determined through the intruder scenarios. Use of potential human intrusion as a means of classifying wastes for disposal has also been used by others.(10,13)

By contrast, it is much more difficult to classify wastes through the use of total activity scenarios such as groundwater migration. Comparatively speaking, impacts from groundwater migration are much more dependent on site specific environmental conditions than the intruder scenarios. In addition, since the potential impacts are a function of the total activity of waste disposed, it is difficult to set concentration limitations for individual radionuclides to meet a specific dose limitation criteria. It would be difficult, based upon groundwater migration considerations, to set concentration limits that can be used by a waste generator to determine the classification of his waste.

It is important to emphasize, however, that this does not mean that groundwater migration from a disposal facility is not an important consideration in LLW disposal. It does suggest that rather than establishing concentration limitations to be met by a waste generator to meet a particular groundwater exposure limitation criteria, it would probably be more useful to set an inventory limitation for a particular disposal facility (based upon site-specific information) for particular radionuclides of concern. Then, if the waste generators were required to report the quantity of the radionuclides of concern which are contained in each shipment of waste, the disposal facility operators could maintain a running inventory of the radionuclides of concern at their particular sites. When the site inventory reaches the established limit for the facility, the disposal facility operator would no longer accept waste streams containing the particular radionuclides of concern. It is expected that such radionuclides of concern would include long lived mobile isotopes such as ^{14}C, ^{99}Tc and ^{129}I.

Potential inadvertent intruder exposures (and maximum radionuclide concentrations corresponding to a given dose conversion criteria) are a function of three general parameters: (1) the time after disposal that the intrusion occurs (the length of the active instititional control period), (2) waste form and packaging properties, and (3) disposal facility design and operating practices. Regulatory requirements can be placed upon these parameters and depending upon the particular requirements placed upon these parameters, a classification system may be developed.

From an analysis of the effect of waste form and packaging properties and disposal facility design and operating practices on impacts from human intrusion, it may be concluded that:

- Barriers may be used to reduce the possibility of human intrusion. These barriers may include disposal at greater depths or emplacement of the waste into a highly engineered facility designed to resist human intrusion (e.g., a hot waste facility).

- If the waste is in a stable waste form that resists dispersion and if the stable waste is placed in a disposal cell which is segregated from unstable waste forms, than potential intruder exposures would be reduced over those exposures expected if the stable wastes were disposed mixed with the unstable wastes.

Based upon establishment of a maximum time for active institutional controls and incorporating the above two conclusions, a waste classification system may be developed based on a maximum exposure limit to a potential inadvertent intruder.

In this work, three generic levels of intruder barriers are considered in detail, which correspond to three general levels of effectiveness against intrusion at three levels of overall costs: (1) no barrier; (2) layering; and (3) hot waste facility.

In the first case, the waste stream is assumed to be disposed in a "regular" manner without consideration of protecting a potential intruder. In the second case, the waste stream is assumed to be disposed at the bottom of the disposal cell, so that at least 5 meters of earth or other (lower activity) waste streams cover the layered waste. In the third case, the waste stream is assumed to be disposed in a hot waste facility, which for this report is taken to be a concrete walled disposal trench. The waste is stacked into the trench, grouting is poured around the waste packages, a concrete cover is then poured over the grouted waste mass, and finally 2 meters of soil is emplaced over the concrete cover. The effectiveness of the hot waste facility is somewhat speculative, but is included to indicate an upper level of protection against an inadvertent intruder that can be achieved through near surface disposal.

In addition, it may be assumed that the operational practice of segregated disposal of stable waste streams from unstable waste streams results in reduced exposures to a potential intruder contacting the stable waste streams -- at least for the first several hundred years following waste disposal. Segregated disposal of the stable waste streams greatly improves the stability of the disposal cells containing the stable wastes, resulting in significantly less water infiltration and subsidence problems for these disposal cells, and less decomposition of the disposal cell contents. Exposures to a potential inadvertent intruder contacting these disposal cells at the end of the active institutional control period would be limited to those acquired during discovery of the waste. It is not credible, for example, to postulate that an intruder would construct a house in, or attempt to grow vegetables in, a disposal cell composed of such wastes as 55-gallon drums filled with concrete.

Finally, consideration needs to be given to the length of time that intruder barriers and segregation of stable wastes serves to reduce or eliminate potential inadvertent intruder impacts. Based on the analysis in reference 3, a time period of 500 years after site closure is used as a limit of the effectiveness of layering and waste segregation. Following this time period, wastes disposed through layering and/or segregation are assumed to be as accessible to an intruder as waste disposed by regular means (i.e., non-segregated shallow land burial). A time period of 1000 years is assumed as a maximum length of time for a hot waste facility to be effective against intrusion.

These concepts are further expanded in the following two sections which present the calculational procedures for determining intruder exposures from the two basic intruder scenarios considered in this appendix. These include the intruder-construction scenario presented in Section 3.4.2 and the intruder-agriculture scenario presented in Section 3.4.3. Following this section is Section 3.4.4 which presents the testing procedure through which the intruder concepts developed in this section are used in the computer codes developed in this work to classify the waste streams for further analysis.

3.4.2 Intruder-Construction Scenario

This is one of the scenarios utilized to determine the classification status of the waste streams -- the other scenario being the intruder-agriculture scenario. This section considers the values of the pathway barrier factors under alternative values of the waste form behavior indices and the disposal technology indices.

This scenario assumes that at some time after the end of operations at the disposal facility, institutional controls breakdown temporarily and an intruder chooses to inadvertantly construct a house on the disposal facility. In so doing, the intruder is assumed to contact the disposed wastes while performing typical excavation work such as installing utilities, putting in basements, and so forth. These typical activities should not be expected to involve significant depths - e.g., in most cases no more than approximately 3 m (about

10 ft). There is, however, a much less likely chance that some excavations could proceed at a lower depth. This could occur, for example, through construction of a sub-basement for a high rise building.

To implement this scenario, the inadvertant intruder is assumed to dig a 3 meter deep foundation hole for the house. The surface area of the house is assumed to be 20 m by 10 m (200 m^2), which is a typical surface area for a reasonably large ranch-style house. The foundation hole is assumed to be 20 m by 10 m (200 m^2) at the bottom and 26 m by 16 m at the top (giving a 1:1 slope for the sides of the hole). The top 2 meters of the foundation is assumed to be cover material and the bottom 1 meter is assumed to be waste. This excavation would result in about 232 m^3 of waste being intruded into.

The equation describing human exposure for the intruder-construction scenario is as follows:

$$H = \sum_n (f_o f_d f_w f_s)_{air} C_w \text{ PDCF-2 } + \sum_n (f_o f_d f_w f_s)_{DG} C_w \text{ PDCF-5} \qquad (3\text{-}1)$$

where H is the 50-year dose committment in mrem, PDCF-2 and PDCF-5 are the radionuclide-specific pathway dose conversion factors which were discussed and presented in Section 2.3, C_w is the radionuclide concentration in the waste, and n denotes summation over all the radionuclides.

The first term of the equation calculates the impacts from the air pathways consisting of exposures due to suspension of contaminated dust into the air: inhalation of the contaminated dust, direct radiation exposure from the contaminated dust cloud, and the consumption of food grown nearby upon which the airborne contamination settles. The second term of the equation calculates the impacts from direct radiation exposure to the wastes during excavation. The values of the barrier factors are examined below in two sections: regular waste disposal, and disposal with barriers against intrusion.

Regular Waste Disposal

The time delay factor f_o is radionuclide-specific and is given by the following equation:

$$f_o = \exp[-\lambda T] \tag{3-2}$$

where T is the time period between the end of active disposal operations and the initiation of the scenario (i.e., IPO plus IIC years), and λ is the decay constant of the radionuclide. This factor is the same for both the air uptake pathways and the direct gamma pathway. The assumed time period is equivalent to the assumption that the intrusion scenario involves the last disposal cell constructed at the site and conservatively neglects the possibility that the intrusion scenario may involve one of the earlier disposal cells.

The site design and operation factor f_d denotes the dilution of the waste due to particular disposal practices regarding waste emplacement. Its value is assumed to be 0.5, 0.75, or 0.5 depending upon whether the waste disposal is random, stacked, or decontainerized, respectively. The effects of other classification tests on f_d are described below.

For the air uptake pathways, the waste form and package factor f_w is given by the following formula:

$$f_w = 10^{(I5-3)} \times 10^{(1-I9)} \tag{3-3}$$

where I5 is the dispersibility index (see Section 3.2.2) and I9 is the accessibility index (see Section 3.2.6). Based on this formula, f_w ranges from a high of 1 to a low of 10^{-5}.(1)

For the direct radiation exposure pathway, only the self-shielding inherent to the particular waste form affects the factor f_w. In this case, f_w is set equal to the following:

$$f_w = \text{Accessibility Multiplier} \times \text{Solidification Multiplier} \quad (3\text{-}4)$$

The modification due to accessibility results from the substantial metal component of some waste streams (see Section 3.3.6). The accessibility multiplier is taken equal to 1 if the index I9 is equal to 1, and it is 0.1 if the index I9 is equal to 2 or 3. The solidification multiplier is assumed to be 0.80 for those streams that are solidified using solidification scenario A or B procedures which contain a significant amount of cement; otherwise, this multiplier is assumed to be unity. Since the streams with an accessibility index different than 1 are never solidified, the minimum value of the factor f_w for the direct radiation exposure pathway is 0.1.

The site selection factor f_s is different for the air and direct gamma uptake pathways of the intruder-construction scenario. For the air uptake pathways, it is the product of the soil-to-air transfer factor T_{sa} (which depends on the environmental characteristics of the region in which the disposal facility is located) with the exposure duration factor (the fraction of a year that the construction takes place). For the direct gamma exposure pathway it is equal to just the exposure duration factor. These factors are detailed below.

In this work, exposure duration is assumed to be 500 working hours for the regular waste disposal. This is equivalent to a construction period of 3 months, which is believed to be reasonably conservative for typical construction. It is believed to be very conservative for activities involving use of heavy construction equipment. This gives a value of 0.057 for f_s for the direct gamma scenario. For the air pathways, this number is multiplied with a soil-to-air transfer factor given by the formula:

$$T_{sa} = [T_{sa}]_o \times (10/v) \times (s/30) \times (50/PE)^2 \qquad (3\text{-}5)$$

where $[T_{sa}]_o$ is equal to 2.53×10^{-10}, v is the average wind speed at the site in m/sec, s is the silt content of the site soils in percent, and PE is the precipitation-evaporation index of the site vicinity indicative of the antecedent moisture conditions (see Appendix A). For the reference disposal facility, these values were determined to be v = 3.61 m/sec, s = 50, and PE = 91, yielding a value of 3.53×10^{-10} for T_{sa} (see Appendix A). For an exposure duration factor of 0.057, this yields a site selection factor of 2.01×10^{-11} for the air uptake component of the construction scenario.

Disposal With Barriers Against Intrusion

The barrier factors f_d and f_s are affected if the waste is disposed using intruder barriers and/or if waste segregation is implemented at the disposal facility. The factor f_d is not affected by regular or layered waste disposal; layered disposal only affects the factor f_s.

For the air uptake pathways, (a) for layered disposal, the factor f_d is multiplied by a factor of 0.1 to indicate the likelihood of contact of the layered wastes by the intruder; and (b) for hot waste facility disposal f_d is multiplied by a factor of 0.01.

For the direct radiation exposure pathway, (a) for layered disposal, f_d is multiplied by a factor of 1/1200 which denotes attenuation of the radiation through a 1 meter thick soil equivalent layer; and (b) for hot waste facility disposal, f_d is multiplied by a factor of $1/1200^2$ which indicates attenuation of the radiation through a layer equivalent to 2 meters of soil (see Appendix A).

The site selection factor f_s is modified only if the waste form is stable and has been disposed of in a segregated manner. The exposure duration factor is reduced from 500 hours to 6 hours for all the uptake pathways.

3.4.3 Intruder-Agriculture Scenario

The intruder-agriculture scenario is the second scenario (the first being the intruder-construction scenario) utilized to determine the classification status of the waste. It is used in three classification tests: (1) for regular waste disposal at the end of IIC years following facility closure, (2) at the end of 500 years for waste streams that have been layered or are stable and segregated, and (3) at the end of 1000 years for wastes that have been disposed into a hot waste facility. Only intruder impacts from regular waste disposal following IIC years is considered below. Intruder impact scenarios at 500 years and at 1000 years are somewhat speculative, and have been conservatively assumed to be similar to those at the end of IIC years.

The intruder-agriculture scenario assumes that at some time after the end of disposal operations, an intruder inadvertently lives on the facility, and consumes food grown on the disposal facility. Farming is a surface activity and generally does not involve disturbing the soil for more than a few feet. As long as a cap of one or two meters is maintained over the waste, then it is very unlikely that agricultural activities would ever contact the waste.

To implement the scenario at the end of active institutional control period, however, a portion of the soil excavated during the intruder-construction activity (232 m^3 of waste and 680 m^3 of cover material) is assumed to be distributed around the completed house. After building the foundations of the house, about 312 m^3 of this soil would be put back in outside and around the cellar walls leaving a volume of about 600 m^3 of soil (of which about 150 m^3 is the original waste/soil mixture) involved in the agriculture scenario. The precise areal extent to which this soil is distributed is somewhat speculative. It is likely, however, that the soil will remain localized; moving even a few cubic yards of soil more than 10 meters usually requires a significant effort. It is assumed in this report that this areal extent is likely to be somewhere between 1000 m^2 and 2000 m^2. That is, the waste/soil mixture is assumed to lie within a radius of 25 meters from the center of the house. The intruder is then assumed to live in this distributed waste/soil mixture and is also assumed to consume vegetables from a small garden located in the waste/soil mixture.

A possible alternative to this scenario is that the waste cover is stripped away by the intruder, and that the intruder lives on and grows and consumes food grown directly in the waste. This does not appear to be as reasonable as the above scenario. At current commercial rates, it costs about $1.07 to move one cubic yard of dirt from one place to an adjacent place with heavy equipment.(12) This implies that to clear 2 meter of cover from 2 acres, the intruder has either invested a sum of about $22,500 or spent a labor equivalent to this sum. This is not a reasonable assumption since no reasonable person is likely to strip and clear away surface soil with the hope of finding a better soil underneath for growing food.

A non-commercial enterprise is therefore assumed for the intruder-agriculture scenario. It appears to be unreasonable to expect that a commercial operator, who would require a substantial investment for a commercial agricultural operation and therefore a clear title to the land, can be an inadvertant intruder.

The inadvertant intruder is assumed to live in a house built on the site, work at a regular job during the day, and spend some of his extra time working in a garden growing vegetables for his own use. His time during a year is assumed to be allocated between various activities as follows:

Activity	Hours/Year
At Home	4380
At Work	2000
Traveling To and From Work	250
Vacation	330
Gardening	100
Outdoors	1700
Total:	8760

In the intruder-agriculture scenario, the inadvertent intruder could be exposed principally by five pathways: (1) inhalation of contaminated dust suspended due to tilling activities as well as natural suspension, (2) direct radiation exposure from standing in the contaminated cloud, (3) consumption of food (leafy vegetables) dusted by fallout from the contaminated cloud, (4) consumption of food grown in the contaminated soil, and (5) direct radiation exposure from the disposed waste volume. For calculational convenience, the first three uptake pathways have been grouped together and denoted as the air uptake pathway. The potential exposures from these pathways are therefore calculated in three groups: air uptake, food (soil) uptake, and direct radiation (volume) exposures. These are then added to arrive at the total potential exposures from this scenario.

In this work, the potential exposures from the intruder-agriculture scenario are calculated using the following equation:

$$\begin{aligned} H = & \sum_{n} (f_o f_d f_w f_s)_{air}\, C_w\, \mathrm{PDCF\text{-}3} \; + \\ & \sum_{n} (f_o f_d f_w f_s)_{food}\, C_w\, \mathrm{PDCF\text{-}4} \; + \\ & \sum_{n} (f_o f_d f_w f_s)_{DG}\, C_w\, \mathrm{PDCF\text{-}5} \end{aligned} \tag{3-6}$$

where H is the annual dose in mrem per year during the 50th exposure year of exposure, PDCF-3, PDCF-4, and PDCF-5 are the radionuclide specific pathway dose conversion factors presented in Section 2.3,

C_w is the radionuclide concentration in the waste, and n denotes summation over all the radionuclides. The values of the barrier factors are presented below.

The time delay factor f_o for this scenario is identical with the construction scenario, and is given by equation (3-2). The site design and operation factor f_d is also determined in the same manner as the construction scenario. In addition, the dilution resulting from mixing of the excavated waste (232 m^3) with the excavated cover soil (680 m^3), which is a factor of about 0.25, is also included in the design and operation factor f_d.

Waste Form and Package Factor

The waste form and package factors for the air uptake and direct radiation exposure pathways composing this scenario are identical with those for the air uptake and direct radiation exposure pathways composing the intruder-construction scenario. However, for the food (soil) uptake pathway, other considerations are applicable. The following formula is utilized to calculate f_w for the food (soil) uptake pathway (also see equation 3-12):

$$f_w = M_o \times t_c \times \mathrm{Mult}(I6,I7,IS) \times 10^{(1-I9)} \qquad (3\text{-}7)$$

where, M_o is the radionuclide-specific leach fractions of unsolidified waste forms (see Section 3.3.3 and 3.5). The contact time fraction t_c is the fraction of time in one year that the waste is in contact with irrigation water, while I9 is the accessibility index (see Section 3.3.6). Mult(I6,I7,IS), which is the reduction due to solidification and the presence or absence of chelating chemicals (see Section 3.3.4), is a function of the leachability index (I6), the chemical content index (I7), and whether the waste streams containing organic chemicals or chelating agents have been segregated from other waste streams (IS).

It appears to be reasonable to assume that only the fraction of radionuclides transferred from the waste to the interstitial water will be accessible to the roots. Inclusion of contact time in the above equation is consistent with this approach. The contact time fraction is conservatively assumed to equal unity in this work. However, this fraction may actually be a very low value in view of the soils likely to be found at most disposal locations. These locations are likely to be at topographic highs whereas the most attractive agricultural soils are found in or adjacent to flood plains.

Site Selection Factor

The site selection factor f_s for the air uptake pathway is similar to the intruder-construction air uptake pathway. However, the soil-to-air transfer factor must be averaged to account for natural resuspension of the soils part of a year. This estimate is calculated by assuming that (1) the construction scenario T_{sa} value of 3.53×10^{-10} (see Section 3.4.2) is applicable during gardening (100 hours), (2) during the time spent outdoors (1700 hours), typical natural outdoor ambient air particulate concentrations of 100 $\mu g/m^3$ are assumed to prevail;(13) and (3) during the time spent indoors (4380 hours), typical ambient indoor concentrations of 50 $\mu g/m^3$ have been assumed.(13) Utilizing a mass loading of 565 $\mu g/m^3$ for the time spent while gardening (see Appendix A) and averaging these values results in a site selection factor value of 3.18×10^{-11}. This may be compared with the site selection factor value of 2.01×10^{-11} calculated for the intruder-construction scenario.

For the food (soil) uptake pathway, f_s is taken to be the fraction of food consumed by the individual that is grown on site. This value is assumed to be 0.5.

For the direct radiation exposure pathway, f_s is equal to the exposure duration fraction multiplied by a correction factor to account for the limited areal extent of the direct radiation source that the intruder is exposed to. Moreover, the fraction of the time the intruder spends in relation to the source must be considered.

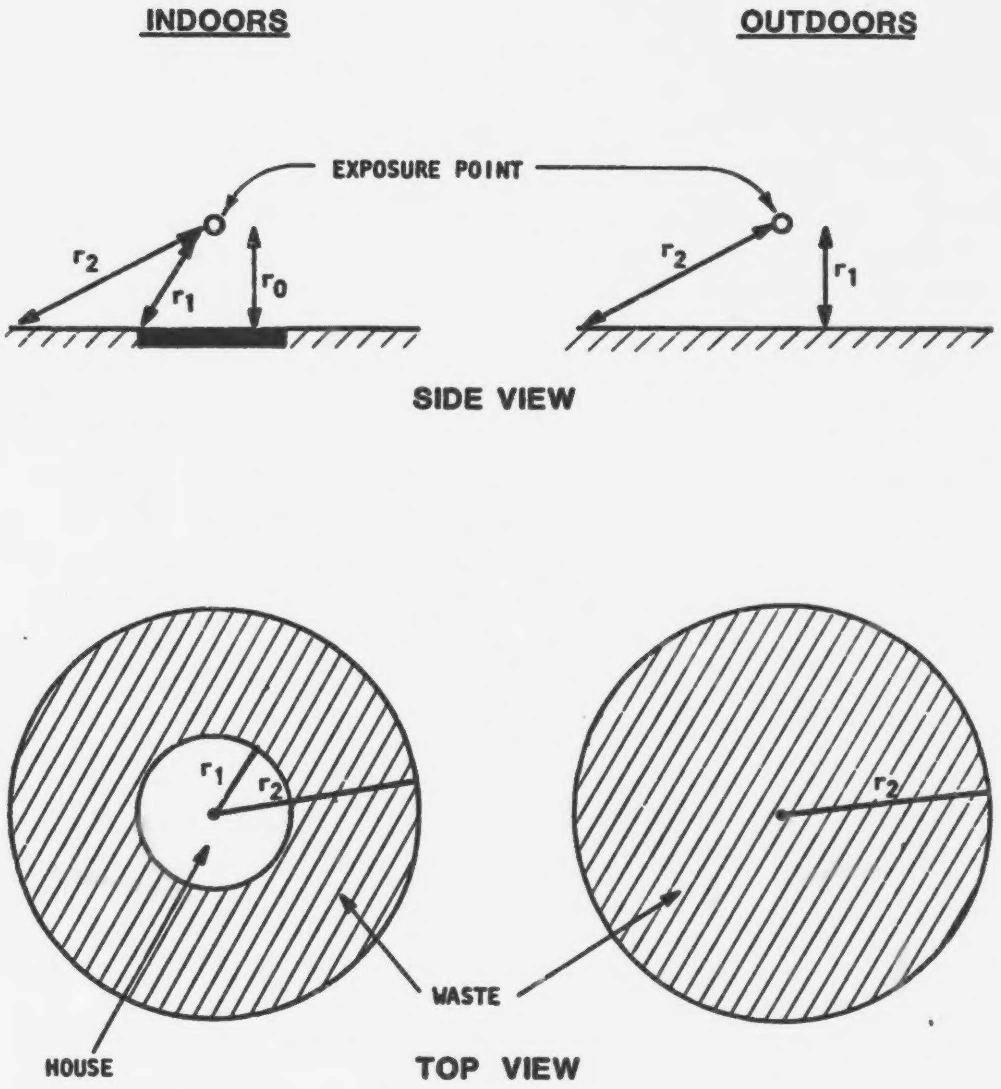
During a year, the intruder is assumed to spend 1800 hours outdoors exposed to unattenuated radiation (100 hours tilling and 1700 hours around the house). During the 4380 hours he spends indoors, he is exposed to attenuated radiation. The correction factor due to the limited areal extent of the radiation source may be estimated utilizing Figure 3.1.

This figure shows that intruder may be assumed to be exposed to a full disk source while outside, and an annular source while inside the house. While he is inside the house, the center of the disk represents the shielding provided by the foundation slab. The contribution to the direct radiation exposure from this center portion may be neglected in comparison with the exposure from the outside of the house. If the foundation slab is a one-foot thick concrete layer, the radiation would be attenuated to about 0.03 of its unshielded value for Cs-137 gamma rays.(14) The correction factor for the areal extent of the annular source may be represented by the following equation:

$$c = [E_1(\mu r_1) - E_1(\mu r_2)] / E_1(\mu r_o) \qquad (3\text{-}8)$$

where c is the dimensionless correction factor, $E_1(x)$ is the first order exponential integral, μ is the linear attenuation coefficient of air in units of m^{-1} (it is taken to be 0.0097 m^{-1} in this report)(14), and the r's are the distances from the exposure point indicated in Figure 3.1 in meters. Details of the derivation of this equation can be found in Appendix A.

For a full disk source (for the time spent outdoors), the radius r_1 in equation (3-8) is replaced by r_o. In order to evaluate the correction factor, these radial distances must be assumed. The


INDOORS
OUTDOORS
EXPOSURE POINT
r_2
r_1
r_0
r_2
r_1
SIDE VIEW
r_1
r_2
r_2
WASTE
HOUSE
TOP VIEW

DIRECT RADIATION EXPOSURE GEOMETRY

FIGURE 3.1

following table gives the value of the exponential integral for some representative distances:

Distance	μr	$E_1(\mu r)$
1 m	0.0097	4.068
8 m	0.0776	2.055
20 m	0.1940	1.335
25 m	0.2425	1.068

For r_0 and r_1, it is reasonable to assume 1 m and 8 m, respectively; 1 m represents the height of the exposed person, and 8 m represents the approximate radius of a 200 m^2 house floor. The value assigned to r_2, however, depends on the areal extent to which waste/soil mixture (600 m^3) has been spread. This mixture will likely be spread unevenly within about a half acre around the house excavation, and the areal extent is likely to be between 1000 m^2 and 2000 m^2. A radius of the above 20 m represents an area of about 1050 m^2 over which the waste is spread, while a radius of 25 m represents an area of about 1750 m^2. A radius of 25 m is utilized in this work.

These assumptions yield a correction factor for the time spent outdoors of about 0.74, and a correction factor for the time spent indoors of about 0.24. Utilizing values of 1800 hours outdoors and 4380 hours indoors yields an site selection barrier factor of about 0.27, which is the value utilized in this report.

3.4.4 Waste Classification Test Procedure

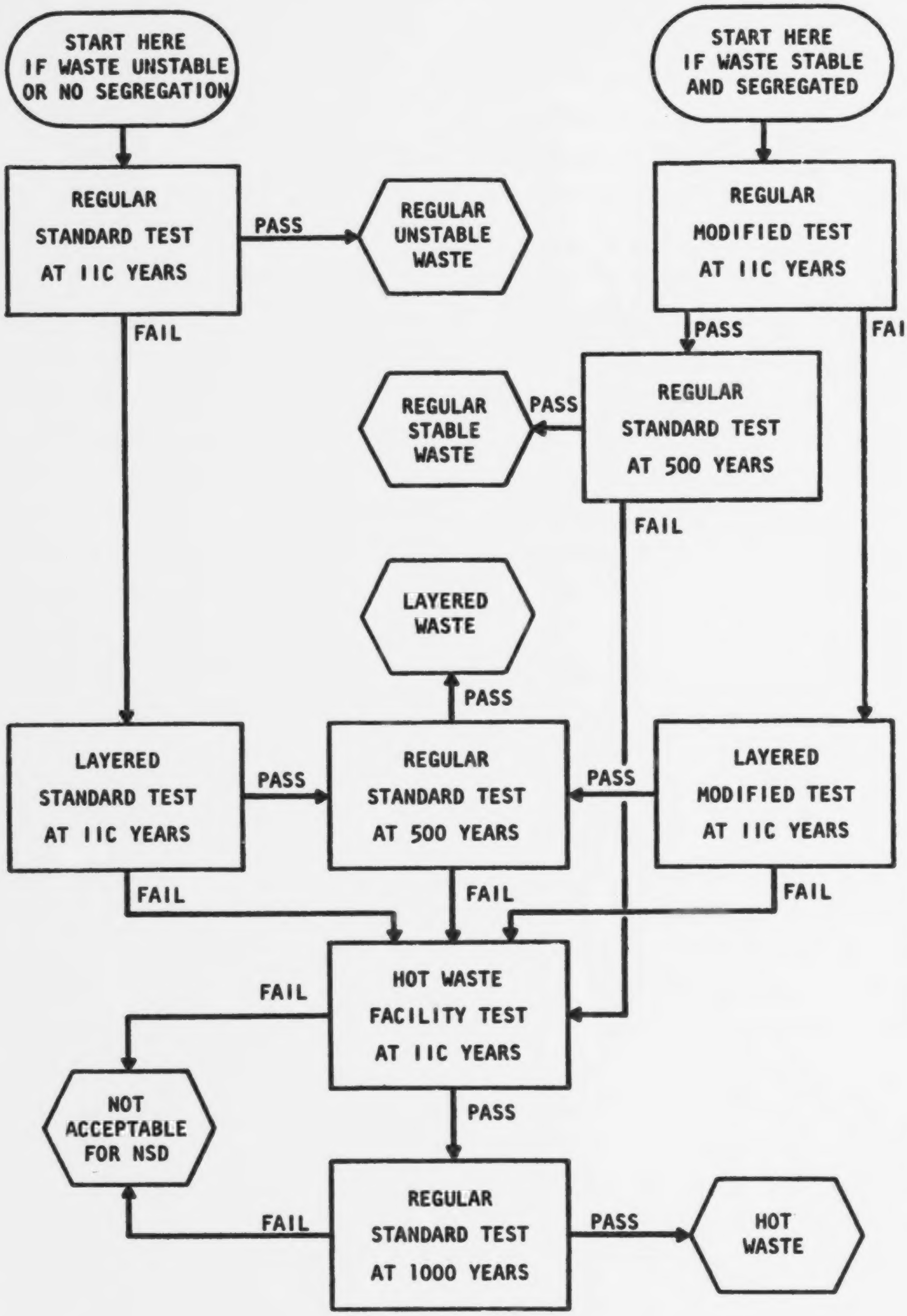
The following section describes the waste classification test procedure developed from the previous sections regarding impacts from potential human intrusion into disposed waste. The test procedure is used in the OPTIONS and GRWATER (see Section 6.0) computer codes which determine radiological, economic, and other impacts from LLW disposal.

In the calculations, the disposal status of each waste stream, denoted by the status index I11, is determined and is used internally in the computer codes. It denotes if any special procedures are required to dispose of the waste stream in a near-surface disposal facility or if the waste is unacceptable for near-surface disposal.

The index, I11, is 1 if the waste is disposable through "regular means," it is 2 if layering of the waste is required, and 3 if the waste is disposed of in a hot waste facility. For disposal by regular means, no special consideration is given to providing barriers against potential inadvertent intruder exposures. Layering of waste streams provides a barrier against an intruder contacting the layered waste streams. Disposal into a hot waste facility provides additional barriers against intrusion. An index value of 0 indicates that the waste is unacceptable for near-surface disposal. The testing procedure utilized in the determination of the disposal status index is presented in Figure 3.2.

Each test consists of successively subjecting a given waste stream to the intruder-construction and the intruder-agriculture scenarios after a given period of time, and determining if the calculated radiological impacts in each scenario for each human organ due to all the radionuclides in the waste stream meet given organ specific "dose limitation criteria." Therefore, there are four basic variables in these tests: (1) the waste status (regular or layered or hot waste test), (2) the type of test (standard or modified), (3) the time after the transfer of the site title to site owner at which the test is applied (after the active institutional control period - denoted by IIC years, or after 500 years, or after 1000 years), and (4) the dose limitation criteria which is applied to all the tests. The first three variables are discussed below.

For a given waste stream, first the regular disposal test is applied at IIC years. This regular disposal test may be either a standard or


START HERE
IF WASTE UNSTABLE
OR NO SEGREGATION
START HERE
IF WASTE STABLE
AND SEGREGATED
REGULAR
STANDARD TEST
AT IIC YEARS
PASS
REGULAR
UNSTABLE
WASTE
REGULAR
MODIFIED TEST
AT IIC YEARS
FAIL
PASS
FAIL
REGULAR
STABLE
WASTE
PASS
REGULAR
STANDARD TEST
AT 500 YEARS
FAIL
LAYERED
WASTE
PASS
LAYERED
STANDARD TEST
AT IIC YEARS
PASS
REGULAR
STANDARD TEST
AT 500 YEARS
PASS
LAYERED
MODIFIED TEST
AT IIC YEARS
FAIL
FAIL
FAIL
FAIL
HOT WASTE
FACILITY TEST
AT IIC YEARS
NOT
ACCEPTABLE
FOR NSD
PASS
FAIL
REGULAR
STANDARD TEST
AT 1000 YEARS
PASS
HOT
WASTE

WASTE CLASSIFICATION TEST PROCEDURE

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FIGURE 3.2

a modified test depending on whether the waste form is stable (I8=1) and the waste streams are being segregated (IS=1) at the disposal site (see Figure 3.2). If the waste is found acceptable during the standard test, then it is classified as regular waste. If the waste passes a modified test, it must also pass a regular standard waste test at 500 years before being classified as regular.

If the waste stream fails any of the above three tests, then it is not regular waste. In this case, the layered disposal tests are applied to the waste stream at IIC years if the layering option is available to the disposal technology case being considered - i.e., if IL is equal to unity. The layered test can also be a standard or modified test depending on the values assigned to the waste stability index (I8) and the segregation index (IS). In both of these cases, a waste stream that passes either of the layered tests is tested again in a regular standard waste test at 500 years before being classified as layered waste.

If the layering option is not available or if the waste stream is found not to be acceptable for layered disposal (i.e., it fails one of the above three tests), then hot waste facility disposal is attempted if that option is available to the disposal case technology being considered - i.e., if IH is equal to 1. There are two tests for the hot waste facility option: one is a special hot waste test at IIC years, and the other is a regular standard test at 1000 years.

If the waste is found to be unacceptable in any of these options - there may be no option but regular disposal, i.e., IL = 0 and IH = 0 - then the waste is considered unacceptable for near-surface disposal for the disposal technology under consideration and for the dose limitation criteria being applied. In this manner the status index I11 is determined and utilized in the total activity scenarios as briefly summarized below and described in detail in Sections 3.5 and 3.6.

If the disposal status of the waste stream is 1 or 2 (regular or layered waste), then no special reduction factors are applied to the groundwater scenarios. However, if the disposal status is 3, then the percolation component of the groundwater scenario is reduced to 25 percent of its minimum value (Section 3.5). This reduction is due to the special measures adopted in the design of a hot waste facility.

If the disposal status of the waste is 1, then no special reduction factors are applied to the exposed waste scenarios. However, if the disposal status is 2, then the wastes are exempted from the erosion initiated exposed waste scenarios (they are beneath a minimum of 6 to 7 meters of other material) and only 1 percent of the waste is assumed to contribute to the intruder initiated exposed waste scenarios (see Section 3.6). For a disposal status of 3, the wastes are exempted from the erosion initiated exposed waste scenarios and only 0.1 percent of the wastes are assumed to contribute to the intruder initiated exposed waste scenarios (see Section 3.6).

As described above, there are five distinct classification tests: regular standard, regular modified, layered standard, layered modified, and hot waste facility. These tests are briefly described below.

Regular Standard Test

In this test, no additional reduction factors are applied to either the intruder-construction or intruder-agriculture scenario. This test may be exercised for regular wastes at the end of IIC years, or to wastes that have passed layered waste tests at the end of 500 years, or to wastes that have passed the hot waste facility test at the end of 1000 years.

Regular Modified Test

The modified test is applied only at the end of IIC years, and it assumes that the waste stream is stable and segregated from unstable waste streams. Therefore, an inadvertant intruder initiating the intruder-construction scenario will clearly realize that wastes are being intruded into, and will not continue any further. This results in a substantially reduced contact time for the intruder-construction scenario.

The regular standard test for the intruder-construction scenario uses a contact time of 500 hours. However, in a regular modified test this contact time is reduced to 6 hours (the actual contact time is likely to be no more than half a working day plus 2 hours to account for direct radiation exposure of the intruder through a reduced thickness of cover material). As a consequence of the discovery that wastes are being intruded into, the intruder-agriculture scenario is eliminated in this test.

Layered Standard and Modified Tests

In the layered standard and the layered modified tests, the intruder-agriculture scenario is not applied since the wastes are likely to be disposed of beneath a minimum of 2 meters of cover and 4 to 5 meters of other regular wastes. No reasonable mechanism after only IIC years can be envisioned that would permit the interaction of these wastes with the environment through an intruder-agriculture scenario. For the intruder-construction scenario, different reduction factors are applied to the two different uptake pathways: air uptake and the direct radiation exposure pathways.

For the air uptake pathway, only 10 percent of the layered wastes are assumed to be accessible to the intruder. This is a very conservative assumption, it is unlikely that even 1 percent of the area exposed during construction will be the layer of waste underneath a minimum 6 to 7 meters of other material. For the direct radiation exposure uptake pathway, the intruder is assumed to be shielded from the layered wastes by at least one meter of soil or equivalent material resulting in a reduction of about 1200 in the radiation intensity (see Appendix A).

For the layered standard test a contact time of 500 hours is assumed. However, for the layered modified test, a contact time of 6 hours is assumed based on the same rationale given above for the regular modified test.

It should be pointed out that all the waste streams that pass these layered tests undergo a regular standard test at the end of 500 years at which time no credit is assumed for layering.

Hot Waste Facility Test

This test is also applied only at the end of IIC years. The rationale presented above for the layered tests is applicable for the hot waste facility which is designed to confine the wastes regardless of cost or land use considerations. Moreover, it in effect takes unstable wastes, and through disposal design makes them into stable wastes for intrusion purposes.

The intruder-agriculture scenario is not considered in the hot waste facility test. For the intruder-construction scenario a reduction factor of 0.01 is applied to the site design factor for the air uptake component, and a reduction factor of $1/1200^2$ is applied for the direct radiation exposure pathway.

Again, it should be pointed out that the waste streams that pass the hot waste facility test are subjected to a regular standard test at the end of 1000 years.

3.5 Groundwater Scenarios

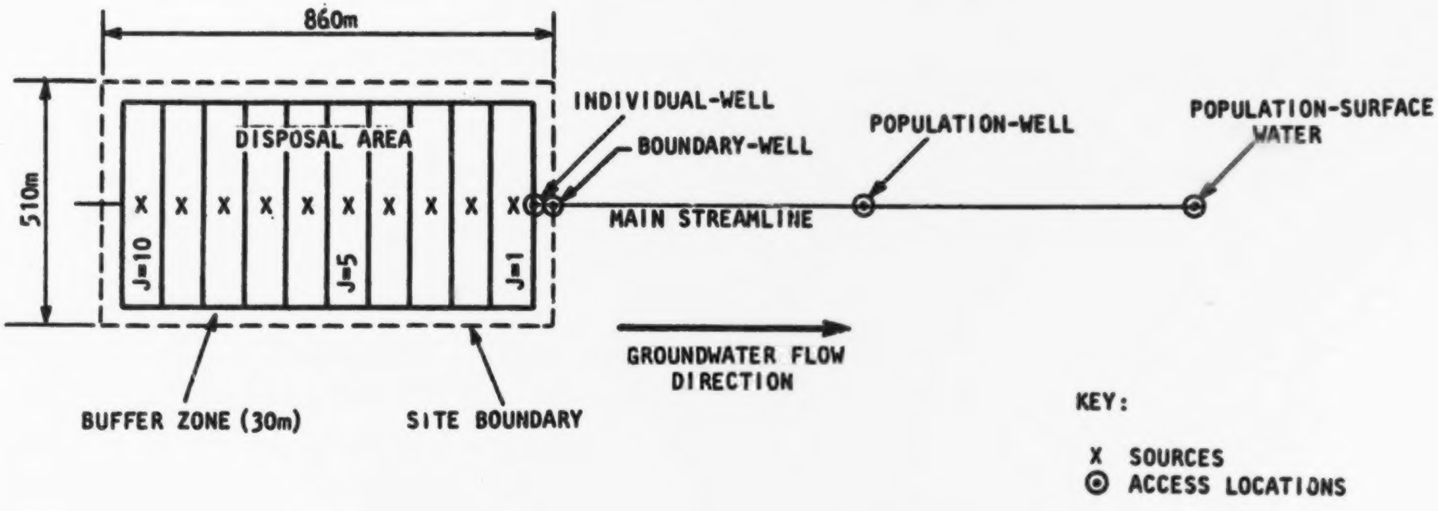
These scenarios calculate the potential impacts resulting from groundwater migration of radionuclides from the disposed wastes to three access locations downstream in the direction of the groundwater flow: a well located either at the boundary of the disposal area or the site boundary, a well located between the disposal facility and the surface hydrologic boundary, and a stream located at the surface hydrologic boundary. Different pathway dose conversion factors are used depending on whether the access location is a well or a stream (see Chapter 2.0). An idealized map showing the geometric relationships between the disposal facility and the access locations are shown in Figure 3.3.

As shown in this figure, the main streamline passing underneath the disposal facility has been straightened out (the longitudinal coordinates are measured along this streamline), and the disposal area (excluding the 30 m wide buffer zone - see Appendix C), which is assumed to cover an area of 450 m x 800 m, has been divided into 10 sectors.

The following equation is used to calculate human exposures which may result from the well access groundwater scenarios:

$$H = \sum_{i} \sum_{n} f_{o} f_{di} f_{wi} f_{si} \; C_{w} \; \text{PDCF-6} \qquad (3\text{-}9)$$

where H is the annual dose rate in mrem per year during the 50th year of exposure, PDCF-6 is the radionuclide-specific pathway dose conversion factor discussed and presented in Section 2.3, C_w is the radionuclide concentration of the waste stream considered, i denotes summation over all the waste streams, and n denotes summation over all the radionuclides. For a surface water access location the dose conversion factor PDCF-7 is substituted instead of PDCF-6. The values of the barrier factors are presented below.


860m
510m
DISPOSAL AREA
X X X X X X X X X X
J=10
J=5
J=1
INDIVIDUAL-WELL
BOUNDARY-WELL
POPULATION-WELL
POPULATION-SURFACE WATER
MAIN STREAMLINE
GROUNDWATER FLOW DIRECTION
BUFFER ZONE (30m)
SITE BOUNDARY
KEY:
X SOURCES
⊙ ACCESS LOCATIONS

GEOMETRIC RELATIONSHIPS
OF DISPOSAL AREA AND DISCHARGE LOCATIONS

FIGURE 3.3

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The time delay factor f_o is assumed to be one. This merely means that the groundwater scenario is assumed to be initated at the close of the operational period.

The site design and operation factor is utilized to incorporate modifications resulting from two of the site design options: use of a hot waste facility, and grouting (the effect of the cover is incorporated into the factor f_w for calculational convenience - see below). If the waste is grouted, then f_d is taken to be 0.1. If the waste is placed in a hot waste facility, f_d is further reduced by a factor of 0.1.

Grouting of the waste minimizes the interstitial void volume, and increases the stability of the waste form and the disposal cell cover. A reduction value of 0.1 is estimated for these effects; however, this value is likely to be conservative since the grouting will probably prevent deterioration of the waste packages, thereby delaying waste/leachate contact. A hot waste facility is a specially designed disposal cell, (e.g., concrete walled trench) for problematic wastes. It has several barriers against percolating precipitation. The reduction factor assumed for this facility is also likely to be conservative.

3.5.1 Source Term

The source term is represented by the waste form and package factor f_{wi}, which has units of m^3/year, and denotes the annual volume of contaminated liquid that leaves the disposal cell. This factor is given by the formula:

$$f_{wi} = f_i \times V_w \times f_c, \qquad (3\text{-}10)$$

where f_i is the fraction of the disposed waste that is in the $(i)^{th}$ waste stream, V_w is the annual volume of water that percolates through the trench cap and contacts the disposed waste/soil mixture, and f_c is the fraction of the waste radionuclide concentration transferred to the leachate.

However, two different source terms may be applicable in calculating f_{wi}: one for regular plus layered wastes (i.e., regular disposal cells), and the other for the hot waste facility (if any). The discussion below primarily considers the calculational procedures for regular disposal cells, calculation of the source term for the hot waste facility cells is mentioned where appropriate.

The first factor f_i is self-evident, it is the ratio of the volume of the waste stream being considered to the entire volume of waste disposed at the either the regular disposal cells or the hot waste facility.

Clearly, the variable (V_w) is simply the percolating infiltration (p) multiplied by the appropriate surface area (S_f). However, again, two different surface areas and percolation rates may be applicable in calculating V_w: one for regular plus layered wastes (i.e., regular disposal cells), and the other for the hot waste facility (if any).

The surface area of the regular disposal cells is equal to the total volume of regular plus layered wastes disposed at the facility divided by the product of the emplacement efficiency with the volumetric disposal efficiency (see Section 3.2.1). The surface area of the hot waste facility is calculated similarly -- the volume of waste disposed at the hot waste facility is divided by the product of the hot waste facility emplacement efficiency (0.75) with its volumetric disposal efficiency (7 m^3/m^2).

For the regular disposal cells, there are several different techniques for calculating the parameter (p) (also called PERC in several references). One of these methods, usually called the water-balance technique, is presented in references 17 and 18 (also see Appendices A and C). The water-balance technique yields a percolation component of about 180 mm of water per year for the reference disposal facility. This value is applicable to those cases where no special effort has been made to emplace a moisture barrier over the waste and to those cases where the barrier integrity cannot be assumed due to instability of the disposal waste. The volume of water percolating in this case will be denoted by V1.

For the cases where there exist special trench covers and where the trench cover integrity can be assumed, the percolation component may be determined by the Darcy velocity of the least permeable stratum between the waste and the atmosphere.(19) The Darcy velocity of a material, with hydraulic conductivity (K) in units of m/yr and unit hydraulic gradient (the most conservative assumption), is equal to K m^3/m^2-yr. This number, however, should be modified by the fraction of each year during which there is at least 0.01 inch of precipitation. Therefore, in this latter case, (p) will be calculated from the following equation:

$$p = K\ (w/365) \qquad (3\text{-}11)$$

where (K) is the hydraulic conductivity of the least permeable layer covering the waste, and (w) is the mean annual number of days with 0.01 inch or more of rainfall (see Appendix A). Assuming that a permeability of 3×10^{-7} cm/sec (about 0.3 ft/yr) is applicable for the least permeable stratum of the designed trench cover, and assuming (for the reference disposal facility) that w is equal to 115, this yields an estimated percolation component of 30 mm. The volume of water percolating in this case will be denoted by V2.

This permeability can be readily achieved through emplacement of a clay layer (materials with permeabilities in the range 10^{-7} to

10^{-9} cm/sec are commonly available), and less readily by using standard soils compaction methods on the existing soils.(20) However, after the active institutional control period, it is likely that as a result of intrusion by humans and/or by plant roots and/or burrowing animals, this low percolation rate may increase. Therefore, a time dependent source term option has been incorporated into the calculations as discussed below and in Section 3.5.3.

In the basic case (no time dependent sources), the above two values for the parameter V_w are used: V1 for the case where no special effort has been made to emplace a moisture barrier over the waste, and V2 for the case where there exists special trench covers and where trench cover integrity can be assumed. However, the specific value utilized for this parameter is also determined by other factors. These include the cover index (IC), the stabilization index (IX), the waste form stability index (I8), and the segregation index (IS). The following table is utilized to arrive at the value of V_w for regular disposal cells:

			Infiltrating Volume	
Cover	Cell Stabilization	Waste Stability	No Segregation	Segregation
Regular	Regular	Stable	2xV1	V1
	"	Unstable	2xV1	2xV1
	Moderate	Stable	1.5xV1	V1
	"	Unstable	1.5xV1	1.5xV1
	Extensive	Stable	V1	V1
	"	Unstable	V1	V1
Thick	Regular	Stable	2xV1	V2
	"	Unstable	2xV1	2xV1
	Moderate	Stable	2xV2	V2
	"	Unstable	2xV2	2xV2
	Extensive	Stable	V2	V2
	"	Unstable	V2	V2

For the hot waste facility (i.e., for those wastes with a "disposal status" index I11 of 3), the above table is ignored, and the infiltrating water volume is taken to be V2/4.

For the time dependent source analysis option, an increase in the infiltration rate is assumed after the active institutional control period as follows. Only the infiltrating volumes that are less than V1 are affected. For 10 percent of the regular disposal cell area which is assumed to be disturbed by intruder activities (about 8 acres), an infiltrating volume of V1 is assumed, and for the rest of the area twice the previous value (i.e., either 4xV2 or 2xV2) is assumed. For the hot waste facility, the infiltrating volume is assumed to become V2 over 10 percent of the area.

The factor f_c represents the fraction of the radionuclides that are transferred from the waste to the leachate. It may be calculated using the following formula:

$$f_c = M_o \times t_c \times \mathrm{Mult}(I6,I7,IS) \times 10^{(1-I9)} \qquad (3\text{-}12)$$

where M_o is the fraction of a specific radionuclide transferred from unsolidified waste to trench leachate due to contact of water at continuous full saturation; t_c is the fraction of a year that the infiltrating volume of water is in contact with the waste; Mult(I6,I7,IS) is the reduction in leachate concentration considering solidification methods and disposal facility operational practices (see Section 3.3.4); and $10^{(1-I9)}$ is the accessibility factor (see Section 3.2.6). These factors are discussed below.

The factor M_o can be estimated by many theoretical methods; however, these theoretical calculations are not consistent with experimental data.(1) In this report, the average upper bounds of the leach fraction for unsolidified waste are estimated assuming that the leachate/waste conditions at Maxey Flats disposal facility and the West Valley disposal facility trenches (both of which can be assumed to be at continuous full saturation) may be used to approximate this bounding fraction. The primary rationale for this approach is that under specified chemical conditions there is an upper limit to the solubility of all elements. The above two disposal sites, because of the presence of organic chemicals and chelating agents and because they can be assumed to be at continuous full saturation, may be assumed to represent extreme leachability conditions. Some researchers in the field believe that use of Maxey Flats estimates represent the best that can be achieved with the available experimental data.(13)

To estimate these ratios, the measured leachate concentrations and the estimated trench inventories from several trenches for each radionuclide are utilized. This estimate takes into consideration the fraction of the leached radioactivity that may be reversibly adsorbed by the interstitial trench soils. These ratios are presented in Table 3-7. Detailed calculations can be found in Appendix A.

The use of the factor M_0, however, necessitates a correction factor to take into account the transient and partially saturated conditions expected in the reference disposal facility. This correction factor is expressed through t_c. This fraction depends on the contact time between the waste and infiltrating water. Assuming that leaching at partial saturation is proportional to the moisture content, the fraction (t_c) may be expressed as the fraction of a year that the percolation component calculated above takes to pass through a given horizontal plane, i.e.,

$$t_c = p/(nv) \qquad (3\text{-}13)$$

where p is the precipitation (in m/yr) that infiltrates and comes into contact with the waste, n is the waste cell effective porosity, and v is the speed of the percolating water (in m/yr). The waste cell effective porosity can conservatively be assumed to be about 25% (partially compacted soils are likely to have higher porosities resulting in lower contact times). The value of v depends on the interstitial soils; a very conservatively low value of 1 ft/day

TABLE 3-7 . Radionuclide Partition Ratios[a] Between Leachate and Waste

Basic Nuclide	Calculated Ratio	Other Nuclides	Assumed Ratio
H-3	1.15	Tc-99	0.115
		I-129	0.115
C-14[b]	5.76×10^{-3}		
Co-60	1.48×10^{-2}	Fe-55	1.48×10^{-2}
		Ni-59	1.48×10^{-2}
		Ni-63	1.48×10^{-2}
		Nb-94	1.11×10^{-2}
Sr-90	9.86×10^{-3}		
Cs-137	1.62×10^{-4}	Cs-135	1.62×10^{-4}
U-238[b]	1.25×10^{-4}	U-235	1.25×10^{-4}
Pu-239[c]	4.67×10^{-4}	Pu-238	4.67×10^{-4}
		Pu-241	4.67×10^{-4}
		Pu-242	4.67×10^{-4}
		Np-237	4.67×10^{-4}
		Cm-243	4.67×10^{-4}
		Cm-244	4.67×10^{-4}
Am-241	4.11×10^{-3}	Am-243	4.11×10^{-3}

(a) Ratio of the leachate concentration in Ci/m^3 to the waste concentration in Ci/m^3. Assumed ratios are estimated based on chemical similarities between the basic nuclide and the nuclide of concern.

(b) Calculated using West Valley leachate concentrations and Maxey Flats inventories.

(c) The calculated ratio includes Pu-238.

(corresponding to a permeability of about 1×10^{-4} cm/sec, an effective porosity of 0.25, and a hydraulic gradient of unity) will be assumed in this report for the reference disposal facility. These calculations yield the values 0.00647 and 0.00108 as the contact time factor for the above percolation cases of 0.18 m/year and 0.03 m/year, respectively.

These values may be modified for soils with different permeabilities by multiplying by the ratios of the respective permeabilities; the contact time factor would increase for soils with low permeabilities, and would decrease for soils with high permeabilities by as much as a factor of 10. For example, an increase in the speed of the percolating water to 10 ft/day (i.e., the percolation goes through an 8 meter deep disposal cell in about 2.5 days) may be expected for sandy soils, similarly, a decrease in the velocity to 0.1 ft/day can be expected for clayey soils.(21)

It should be noted that an increase or decrease in the volume of percolating water affects the contact time linearly, and this has to be incorporated into the formulation. Therefore, the source term is a quadratic function of percolation. For example, for the worst case scenario (i.e., 2xV1 percolation), the above contact time of 0.00647 is multiplied by a factor of 2 yielding a total increase in the source term by a factor of 4.

The last two factors in equation (3-18) are the multipliers due to waste solidification and facility operating practices, and due to the relative inaccessibility of activated radioactivity in metals waste streams. The multiplier due to waste solidification and facility operating practices has been discussed in Section 3.2.3, and the table detailing the Mult(I6,I7,IS) factor in Section 3.4 is applied identically to this scenario. The multiplier for activated metal waste forms has been discussed in Section 3.3.6.

3.5.2 Migration Reduction Factor

The waste form and package factor, as expressed above, yields the total (in m^3/yr) source term that can be expected from a given waste stream, and the product of the radioactive concentration with the source term gives the annual release (in Ci/yr). This source term must be related to the radionuclide concentrations at the groundwater discharge locations. This relation is expressed through the site selection factor (f_s) in units of yr/m^3. This factor, which has also been referenced as the "confinement factor" or reduction factor,(18) is the ground water migration analog of the (X/Q) dispersion factor in meteorological diffusion calculations (see Appendix A).

Dozens of models, both analytical and numerical, have been developed to forecast the probable extent of radionuclide migration (sometimes called mass transport) and the associated environmental impact. Reviews of some of the available simulation techniques are presented in references 22, 23, and 24.

Analytical models simulate the mass transport processes using a series of algebraically solvable mathematical equations having parameters that are homogeneous or can be homogenized. They are best used under conditions where little hydrogeologic data exists, where the existing site parameters can be represented by space- and time-averaged quantities, where the stratigraphy of the site is so complex as to preclude cost-effective detailed data accumulation or an accurate consideration of the spatial variation of parameters (e.g., laterally discontinuous lenses of material interbedded with irregular stratigraphy) or, as is the case in this report, where the study is concerned with generic sites and designs. Numerical models are preferable if the geologic setting of the site is relatively complex (an exception is the complexity level discussed above) and site-specific data defining significant space- and/or time-variation of the site parameters is available.

The analytical simulation assumes that the porous medium consists of an unsaturated and a saturated zone, each of which is stationary, homogeneous and isotropic, and the fluid moving through these zones is incompressible and of constant viscosity.

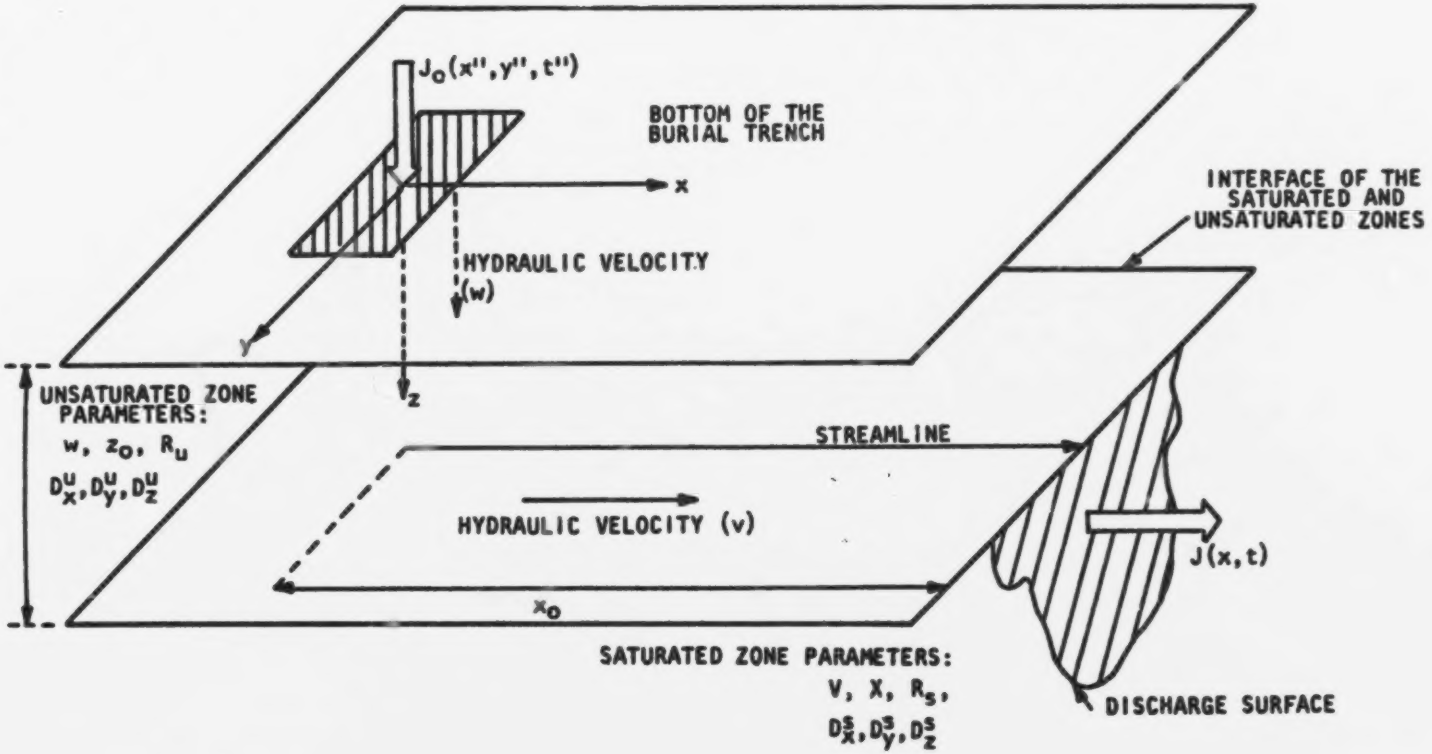
The source term is assumed to be given by J_0 (which is equal to f_{wi} multiplied by the waste concentrations in this report), whose units are in curies/year. The source term is assumed to exist during the source duration time (T). A geometry of the migration problem is shown in Figure 3.4.

The measurable hydrogeological parameters that must be included in an accurate simulation of mass transport are: the geometry of the problem (e.g., the travel distance, x, to a biota access location), the decay constant of the radionuclides, the hydraulic velocities of the fluid (e.g., v), the dispersion characteristics of the medium, and the retardation coefficients of the radionuclide-medium interaction. The space- and time-averaging of the above parameters, if necessary, may be accomplished in a straightforward manner (see Appendix A).(18)

As discussed in Section 2.4, it can be shown that the time dependent site selection factor is given by:(18)

$$f_{si} = [r_g/Q] \sum_j r_{tij} \qquad (3\text{-}14)$$

where (Q) is the dilution factor in units of volume/time; the factor r_g is the time independent reduction factor due to the geometry of the problem (i.e., the spatial relationship of the burial trench and the discharge location); j denotes the longitudinal sectors of the disposal facility shown in Figure 3.3; and r_{tij} is the reduction factor due to migration and radioactive decay which depends on both space and time, including the sectors of the disposal facility and the duration of the source term (T_i).


$J_0(x'', y'', t'')$
BOTTOM OF THE BURIAL TRENCH
x
INTERFACE OF THE SATURATED AND UNSATURATED ZONES
HYDRAULIC VELOCITY (w)
y
z
UNSATURATED ZONE PARAMETERS:
w, z_0, R_u
D_x^u, D_y^u, D_z^u
STREAMLINE
HYDRAULIC VELOCITY (v)
$J(x, t)$
x_0
SATURATED ZONE PARAMETERS:
$V, X, R_s,$
D_x^s, D_y^s, D_z^s
DISCHARGE SURFACE

GEOMETRY OF GROUNDWATER MIGRATION

FIGURE 3.4

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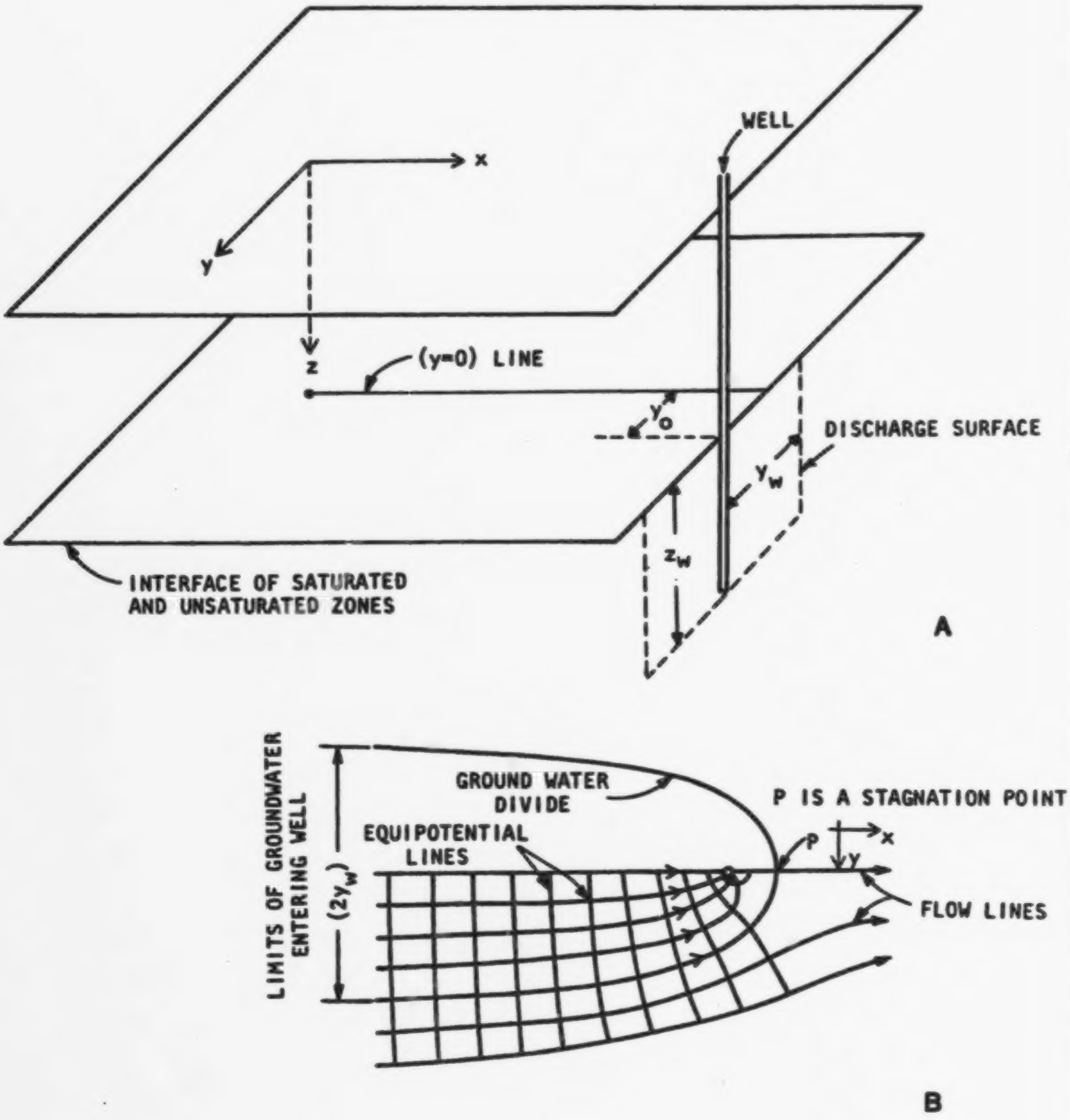
Geometric Reduction Factor - r_g

This reduction factor is assumed to be independent of the characteristics of the waste streams. It is also independent of the longitudinal relationship of the disposal facility with the access location. This results in a second order approximation since the transverse dispersion of the radionuclides depend on the travel time between the disposal facility and the discharge location, and the factor r_g is a measure of the transverse dispersion of contaminants.(18) However, this effect is negligible when compared with the primary effect of the transverse extent of the disposal area (assumed to be 450 meters) in relation to the access location. This primary effect is quantified through r_g.

In this report, it is conservatively assumed that the biota access location is always on the main streamline from the disposal facility (see Figure 3.1). That is, it is located on the streamline that passes through the center of the disposal facility. In off-center location cases, this effect would be expressed through the factor r_g as well.

The maximum value of r_g is unity; it is different from unity only in the well access cases. In the well access cases, it depends on the radius of influence resulting from the pumping rate. In other words, depending on the pumping rate of the well, some or all of the radioactivity released across the entire disposal facility width of 450 meters may be pumped up with the well water. An idealized pumped well geometry illustrating these concepts is presented in Figure 3.5.

The generalized formulae for the reduction factor r_g are presented in reference 18 and are summarized in Appendix A. However, they are unnecessarily complicated for the generic cases being considered. The following simplified equation is used in this work:


WELL
x
y
z
(y=0) LINE
y_o
DISCHARGE SURFACE
y_w
z_w
INTERFACE OF SATURATED AND UNSATURATED ZONES
A
LIMITS OF GROUNDWATER ENTERING WELL
$(2y_w)$
GROUND WATER DIVIDE
P IS A STAGNATION POINT
EQUIPOTENTIAL LINES
P
x
y
FLOW LINES
B

WELL CASE : A) SIDE VIEW
B) PLANVIEW WITH STREAMLINES

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FIGURE 3.5

$r_g = 1$: surface water access

$r_g = 2\, y_w/L$: well water access

where y_w is the pumping radius of the well (see Figure 3.5), and L is the transverse width of the disposal area. The pumping radius of the well is dependent on the groundwater velocity, and may be represented by the following equation:(18)

$$y_w = Q \,/\, (2\, z_w\, n\, v)$$

where Q is the pumping rate of the well, z_w is the pumping depth (minimum depth of the well below the interface of the saturated and the unsaturated zones), n is the porosity of the stratum being pumped, and v is the groundwater velocity.(18)

For most locations where a disposal site may be located, the groundwater velocity is likely to be low (partially intentionally, partially because the site is likely to be located at a topographic high which implies a low hydraulic gradient). In order to get water yields from such a well sufficient to meet the needs of an individual, the pumping radius would be expected to be very high. For example, for a pumping rate of 7700 m^3/year (representing the basic annual needs of a single farmer - see below and Appendix A), in a medium with an effective porosity of 0.25, a groundwater speed of 1.5 m/year, and a pumping depth of 10 meters, the pumping radius turns out to be about 1000 meters (implying an r_g value of unity). If equal values for the pumping depth and the pumping radius are assumed, these values turn out to be about 100 meters (implying an r_g value of 0.45).

In this report, the dilution factors that have been assumed imply that in most cases the pumping radius is likely to be high. Therefore, the geometric reduction factor r_g is conservatively assumed to be unity in all cases for the reference disposal facility.

Dilution Factor - Q

The dilution factor is independent of the characteristics of the waste stream and the geometrical relationship of the disposal facility with respect to access location. The factor Q may be the pumping rate of a well or the flow rate of a stream.

In this work, the dilution rates assumed are 200,000 m^3/year (about 100 gpm - gallons per minute) for the population well scenario and 4.5×10^6 m^3/year (about 5 cfs - cubic feet per second) for the surface stream scenario. Small farming communities that utilize groundwater for their needs usually have wells that range from 100 gpm to 1000 gpm depending on the population.(18) A stream flow rate of about 5 cfs is selected since a stream with flow rate below this value is very unlikely to be used for human consumption. For example, Rock Lick Creek nearby the Maxey Flats disposal facility has an annual average flow rate of about 7 cfs, but it is not used for human consumption; it is used only for livestock.(25)

For the individual well and boundary well scenarios, Q is given by the assumed total volume of percolating infiltration through the disposal facility area. In other words, the source term J_0 calculated in the previous section is diluted by a minimum volume of water infiltrating through the disposal area and recharging the groundwater.

The primary rationale for this procedure is that the source term will be mixed with an appropriate volume of water in the groundwater regime. In past studies,(10) this volume has been assumed to be the annual aquifer flow rate underneath the site which necessitates assumptions on the aquifer thickness (or radionuclide mixing depth) and velocity. Furthermore, this approach necessitates the assumption that the radionuclide source term is mixed homogeneously throughout the aquifer thickness (or the assumed mixing depth). In this report, this dilution volume is estimated to be the natural percolation of the disposal site vicinity multiplied by 352,000 m^2, which is the disposal area required for the reference facility. This value is conservative since it is likely that there may be substantial contribution to groundwater from areas upstream/downstream of the disposal facility.

There is a lower bound, however, for the value of the dilution volume for the intruder well and boundary well scenarios. Otherwise the above technique would give invalid results for disposal facilities located in regional environments in which the natural percolation is very low, e.g., an arid western environment. The lower bound dilution rate in this report is taken to be 7700 m^3/year (3.84 gpm) , which represents the needs of a single person living in a rural area.(26)

Migration Reduction Factor - r_{tij}

This factor depends on the time that the exposure is assumed to occur, the duration of groundwater travel between the j^{th} longitudinal section of the disposal facility and the access location, the retardation capability of the soils (radionuclide dependent), the duration of the assumed source term, and the waste stream characteristics. The longitudinal extent of the disposal facility is considered by dividing the facility into 10 sectors and summing the contributions from each sector (assumed to be equal) to obtain the concentrations at the discharge location. Detailed formulae for this factor can be found in Appendix A. In this work, the following formula is used for the migration reduction factor r_{tij}:

$$r_{tij} = [\exp(-\lambda t)/(J \mathrm{x} T_i)] \mathrm{x} [\, F_j(t) - F_j(t-T_i) \,] \qquad (3\text{-}15)$$

where λ is the decay constant of the radionuclide; t is the time at which the migration reduction factor is applicable, J is the total number of longitudinal sectors the disposal site has been divided into, which is 10 in this work (see Figure 3.3); T_i is the source duration factor for the i^{th} waste stream, and j denotes the sector of the disposal site. The function $F_j(t)$ is given by the following formula (see Appendix A):(18,27)

$$F_j(t) = 0.5 \times U(t) \times [\mathrm{erfc}(X_-) + \exp(P_j)\ \mathrm{erfc}(X_+)] \qquad (3\text{-}16)$$

$$X_{\pm} = \frac{\sqrt{P_j}}{2} \ \frac{1 \pm t/(Rt_{wj})}{\sqrt{t/(Rt_{wj})}} \qquad (3\text{-}17)$$

where U(t) is the unit impulse function that is zero for a negative argument and is equal to unity otherwise; t_{wj} is the water travel time between the disposal sector being considered and the access location, P_j is the Peclet number for the distance between the disposal sector and the access location, R is the retardation coefficient of the radionuclide, and erfc(x) is the complement of the error function and is given by the formula:(28)

$$\mathrm{erfc}(x) = 1 - \int_0^x (2/\sqrt{\pi}) \exp(-t^2)\, dt \qquad (3\text{-}18)$$

The retardation coefficients R that are utilized in the above equations depend on the radionuclide as well as the geochemistry of the soils and the transporting groundwater. They are indicative of the reversible ion exchange capability of the soils and represent the ratio of the radionuclide velocities in the soil to the groundwater velocities. The cation exchange capacity of the soils is a parameter which can be used to estimate the retardation coefficients of the soils, since retardation coefficients are usually linearly depend on the cation exchange capacity. Five sets of retardation coefficients are utilized in this work.(29,30) These coefficients are presented in Table 3-8.

The clay and mineral content of the soils, in addition to the groundwater chemistry, significantly affects the retardation capability of the soils. The retardation coefficients given in Table 3-8 span the general range of values that are encountered in groundwater migration

TABLE 3-8 . Sets of Retardation Coefficients[a] Used in Impacts Analysis

	Assumed Retardation Coefficients					
Nuclide	Set 1	Set 2	Set 3	Set 4	Set 5	BNWL[b]
H-3	1	1	1	1	1	1
C-14	10	10	10	10	10	10
Fe-55	630	1290	2640	5400	11050	3333
Ni-59[c]	420	860	1750	3600	7350	333
Co-60	420	860	1750	3600	7350	333
Sr-90	9	18	36	73	146	100
Nb-94	1000	2150	4640	10000	21500	10000
Tc-99	2	3	4	5	6	1
I-129	2	3	4	5	6	1
Cs-137[c]	85	173	350	720	1460	1000
U-235[c]	840	1720	3520	7200	14730	14286
Np-237	300	600	1200	2500	5000	100
Pu-238[c]	840	1720	3520	7200	14730	10000
Cm-243[c]	300	600	1200	2500	5000	3333
Am-241[c]	300	600	1200	2500	5000	10000

(a) Sets 1 and 4 are values obtained from reference 29, except for the radionuclides Nb-94 and U-235. These values are based on comparative retardations given by the BNWL column (reference 30). Sets 2 and 3 are obtained as geometric midpoints of Sets 1 and 4, and Set 5 is similarly calculated, i.e,:

Set 2 = Set 1 x Cube Root of (Set 4/Set 1),
Set 3 = Set 2 x Cube Root of (Set 4/Set 1),
Set 5 = Set 4 x Cube Root of (Set 4/Set 1).

(b) These values are given in reference 30 for desert soils with a moderate cation exchange capacity of about 5 meq/100 g. They have been used as a guide to fill in missing values.

(c) Coefficients for other isotopes of these elements are assumed to be the same.

calculations. The first set is representative of coefficients for sandy soils with low to moderate cation exchange capacities, and is assumed to represent the lower bound of retardation coefficients used in this generic analysis. The fourth set is representative of coefficients for clayey soils with moderate to high cation exchange capacities, and is assumed to represent the best conditions that can be routinely achieved. In between these two sets, two other sets have been postulated and have been calculated utilizing the geometric mid-points of sets 1 and 4. The third set of coefficients have been assumed to be applicable to the reference disposal facility. A fifth set of coefficients has been also calculated for use in special cases.

The source duration factor T_i for the i^{th} waste stream is determined by dividing the total activity in the stream with the annual release fraction which is given by the factor f_{wi} multiplied by the radionuclide concentration. This calculation conservatively neglects the depletion of the radionuclide inventory at the disposal facility by previous releases.

The groundwater travel times t_{wj} depend on the distance between the disposal facility sector being considered and the discharge location. The travel time between the first sector and the access location is denoted by t_{w1}. It is assumed for the reference disposal facility that groundwater takes 10 years to traverse the unsaturated zone. The assumed values of t_{w1} for the reference disposal facility are presented below:

Location	Travel Time - t_{w1}
Intruder-Well	42 years
Boundary-Well	66 years
Population-Well	400 years
Surface Stream	800 years

The groundwater travel time between two adjacent sectors (a distance of 80 meters for the reference disposal facility) is assumed to be 64 years (corresponding to a speed between two adjacent sectors of

1.25 m/year) and, to determine the groundwater travel times for the other sectors, an appropriate multiple of the travel time is added to the t_{w1}. It should be pointed out that using groundwater travel times (and the Peclet numbers discussed below) as the primary variables on which the migration analysis is based, implicitly allows for a sensitivity analysis. Sites with differing environmental parameters may lead to similar radionuclide concentrations at the access locations. For example, similar results would be obtained if the groundwater velocity is twice as high and the distance to the access location is twice as large. Similarly, a larger unsaturated zone travel time (water speeds of the order of 10^{-2} feet/year are frequently encountered)(23) would compensate for a shorter saturated zone travel time.

The Peclet number, P_j, is the distance to the access location divided by the longitudinal dispersivity of the medium. Peclet numbers for the distances between the sectors are determined in a manner similar to the travel times. For the reference disposal facility, a value of 1600 is added for two adjacent sectors to the Peclet number for the first sector P_1, which is assumed to be the following:

Location	Peclet Number - P_1
Individual-Well	1300
Boundary-Well	1900
Population-Well	10000
Surface Stream	20000

The discussion presented above for the variation of travel times is applicable to the selected Peclet numbers as well. In this manner, the unsaturated and saturated zones are considered as a single unit. The primary justification for this approach is the generic nature of the analysis. Moreover, as long as the groundwater travel time in the unsaturated zone is added to the saturated zone travel time, and the Peclet numbers for the two zones are added, the above is a valid approximation to the alternative of considering saturated and unsaturated zones as two units with the ensuing complications. Such a treatment can be found in a previous work by the authors.(18)

3.5.3 Special Cases

This section considers three special cases utilized in the groundwater migration calculational procedure: the maximum concentration case, the time dependent source analysis, and high integrity containers. These cases are considered below.

Maximum Concentration Case

The equations given above can be used to determine radionuclide concentrations at a particular access location as a function of time. It may also be of interest to determine the maximum concentration of a particular radionuclide at a particular access location over all time.

The maximum radionuclide concentration at the particular access location considered may occur long after the initiation of the scenario, and becomes significant for those radionuclides that have high retardation coefficients and very long half lives -- e.g., U-235, U-238, Pu-239. For this special case, only the reduction factor r_{tij} is affected in the above formulation and a modification of equation (3-14) is necessary to calculate the maximum concentrations. The equation utilized in this work is:$^{(18)}$

$$f_{si} = [r_g \; r_i]/Q \qquad (3\text{-}19)$$

where r_g and Q are as defined previously, and r_i is the time independent maximum value of the migration reduction factor r_{tij}. The parameter r_i is given by the following equation.

$$r_i = \text{Maximum of } [r_{i1}, r_{i2}, \ldots, r_{i10}] \qquad (3\text{-}20)$$

where

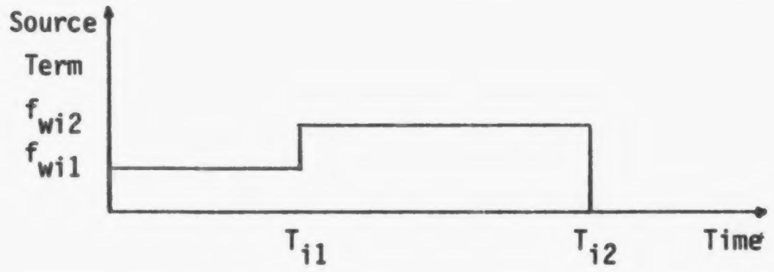
$$r_{ik} = k \times [\exp[-\lambda R t_{wk}]/(J \times T_i)] \qquad (3\text{-}21)$$

where the above variables J, T_i, λ , R, and t_{wk} denote the same parameters defined previously.

Time Dependent Sources

Although a disposal facility will be designed and operated so that infiltration of rainwater will be minimized, it is possible that sometime after the disposal facility is closed, active institutional controls may breakdown and potential inadvertant intrusion into part of the disposed wastes may occur and, as a result, rainwater infiltration may increase. Similarly, a breakdown in institutional controls may lead to intrusion into the waste mass by deep-rooted plants and burrowing animals which also may lead to an increase in rainwater infiltration. This potential increase in infiltration would result in a corresponding increase in the groundwater migration source term. A calculational procedure to account for this time dependent source term is presented below.

For the case of the time dependent source term analysis, two different source magnitudes are considered. The source term is assumed to increase after the end of the active institutional control period as represented by the following histogram:



Two source terms, denoted by f_{wi1} and f_{wi2}, are calculated using equation (3-15). These source terms are used in conjunction with two source duration times denoted by (T_{i1}) and $(T_{i2}-T_{i1})$. The first source term is applicable during the duration time of T_{i1} years (equal to or less than IPO+IIC - see Section 3.1), and the second source term is applicable during a duration time $T_{i2}-T_{i1}$. The second source duration time is calculated by substracting the radioactivity that has migrated from the site during the first source duration time from the activity inventory of the site (the area under the above histogram), and dividing the remaining site activity inventory by the second source term. In other words, it is calculated by the formula:

$$T_{2i} = T_{i1} + f_{wi1} \times (TDUR - T_{i1}) / f_{wi2} \tag{3-22}$$

where TDUR represents the source duration time if f_{wi1} were the source term during the entire period. In other words, TDUR is the duration time for the time independent source term analysis and TDUR times f_{wi1} times C_w is the entire site inventory of the radionuclide being considered.

For calculational convenience, the source term for this analysis is taken to be equal to f_{wi1} for all times, and the effect of the increased source term after time T_{i1} is incorporated into the factor r_{tij}. The following equation is used to calculate the modified factor r_{tij}:

$$r_{tij} = [\exp(-\lambda t)/(J \times TDUR)] \times \Big[F_j(t) - F_j(t-T_{i1}) + (f_{wi2}/f_{wi1}) \times [F_j(t-T_{i1}) - F_j(t-T_{i2})] \Big] \tag{3-23}$$

where $F_j(t)$ is the function defined previously by equation (3-19), and where the variables λ , J, TDUR, T_{i1}, T_{i2}, f_{wi1}, and f_{wi2} are as defined previously. For cases where the source is depleted within the active institutional control period (TDUR is less than IPO+IIC), or for cases where the percolation volume at the disposal facility is greater than or equal to V1 (see Section 3.5.1), this analysis is ignored.

High Integrity Containers

High integrity containers are packages which are designed to preclude waste/trench water contact for long periods of time.(1) This time period may vary from a few years to several hundred years. The effect of this delay due to use of high integrity containers is incorporated into the analysis by adding the delay time to all the groundwater travel times for the selected waste streams. This procedure results in accurate consideration of the effects of this special case -- i.e., the time delay factor f_0 is waste stream independent, whereas high integrity containers may be applied to only certain waste streams.

3.6 Exposed Waste Scenarios

In these scenarios, some or all of the surface area of the disposed waste is assumed to be exposed through some means. The mechanism that initiates uncovering of the waste can be either the erosion of the waste cover by surface water or wind action, or intruder activities such as construction or agriculture. Similarly, there are two exposed waste surface scenarios depending on whether the transfer agent is wind or surface water, the corresponding biota access location can be either an off-site surface water body (through surface water runoff) or off-site air (through wind suspension and transport). Therefore, there are four exposed waste scenarios: intruder-air, intruder-water, erosion-air, and erosion-water.

Only those wastes that have been disposed through regular disposal designs are considered in the erosion initiated scenarios. Waste that is layered (disposed of at the bottom of the disposal cells), and waste that is disposed of in a hot waste facility are assumed not to be exposed to the atmosphere for the erosion-initiated scenarios. However, all the wastes are considered in the intruder-initiated scenarios. The following equations are utilized to calculate human exposures resulting from these scenarios. For the water transport and access case:

$$H = \sum_{i} \sum_{n} (f_o f_{di} f_{wi} f_{si})_{wat} \; C_{wi} \; \text{PDCF-7} \qquad (3\text{-}24)$$

and, for the air transport and access case:

$$H = \sum_{i} \sum_{n} (f_o f_{di} f_{wi} f_{si})_{air} \; C_{wi} \; \text{PDCF-8} \qquad (3\text{-}25)$$

where H is the 50th year annual dose in mrem/year after 50 years of exposure, PDCF-7 and PDCF-8 are the radionuclide specific pathway dose conversion factors discussed and presented in Section 2.3, C_{wi} is the radionuclide concentration in the i^{th} waste stream, n denotes summation over all the radionuclides, and i denotes summation over all the waste streams. The values of the barrier factors are presented below.

The time delay factor (f_o) is defined by:

$$f_o = \exp[\, - \lambda \, T \,] \qquad (3\text{-}2)$$

where T is the delay time, and λ is the decay constant. For the intruder-initiated exposed waste scenarios, the delay time (T) is taken to be the period between the cessation of active disposal operations and the end of the active institutional control period. For the erosion-initiated exposed waste scenarios, it is taken to be dependent on the cover thickness utilized -- i.e., it is a function of the disposal technology index IC. The following table presents the values asumed for the initiation of the erosion scenario:

IC	Delay Time
1	2000 years
2	3000 years
3	10000 years

These values are extremely conservative. Previous estimates on the erosion potential of adequately emplaced cover materials have ranged from 1000 years to 10,000 years to erode 1 meter of soil cover.(13)

After consideration of the variability of this time period, reference 13 assumes a time of 2000 years to erode through 2 meters of cover material. This is the value utilized in this work.

The site design factor (f_{di}) is defined as the fraction of the exposed area that is waste, and will be assumed to be independent of the waste stream considered. Therefore, it will be taken to be proportional to the emplacement efficiency of the waste; however, in this case the percentage of the land area in between the disposal cells that have not been utilized for waste disposal must be considered -- i.e., the land-surface utilization rate (see Section 3.2.2). Therefore, the site design factor is taken equal to the product of the emplacement efficiency (0.75 for stacked disposal and 0.5 for other emplacement cases) with the land-surface utilization rate of the design option (for reference disposal facility design it is conservatively estimated to be 0.90).

The waste form and package factor (f_{wi}) denotes the total volume of the soil-waste mixture mobilized by the transfer agent per year. In this report, it may be empirically broken down into the following components.

$$f_{wi} = E \times (A/d)_i \qquad (3\text{-}26)$$

where:

E = soil-waste mixture mobilization rate (in g/m^2-yr) which will be taken to be independent of the waste stream.

A_i = total area of the soil-waste mixture (in m^2) that can be identified with the $(i)^{th}$ waste stream.

d_i = density of the soil-waste mixture (in g/m^3) that can be identified with the $(i)^{th}$ waste stream.

This equation is applicable for both the wind transport scenario and the surface water scenario. Specific values of the parameters and the site selection factor f_{si} are discussed below.

3.6.1 Wind Transport Scenario

For the intruder-initiated scenarios, the factor E can be calculated based on use of the soil-to-air transfer factor (see Appendix A). It may be taken as the time weighted average of the dust mobilization rate (0.218 mg/m^2-sec) resulting from construction or gardening activities such as tilling and the natural wind mobilization rate of 4.1×10^{-4} mg/m^2-sec (see Appendix A).

Both the intruder-construction and the intruder-agriculture scenarios are used in the intruder-initiated exposed waste scenario depending on the disposal status of the waste: regular unstable and layered unstable wastes are subjected to the agriculture scenario, and regular stable, layered stable, and hot waste facility wastes are subjected to the construction scenario. However, only 1 percent of the layered unstable wastes are assumed to contribute to the agriculture scenario, while only 1 percent of the layered stable wastes and 0.1 percent of the hot waste facility wastes are assumed to contribute to the construction scenario. Moreover, the duration of the exposed waste scenario is modified by the duration factor of 6 hours (instead of 500 hours) for the stable wastes. Furthermore, about 1800 m^2 of waste area is exposed continuously in the agriculture scenario with only a fraction used for gardening, and 200 m^2 of area is exposed for 500 hours for the standard construction scenario.

In order to simplify the complicated procedure required to estimate the factor E for the above conditional cases, a basic mobilization rate is assumed to be applicable to all the cases with correction factors applied to each waste stream as appropriate for the special conditions outlined above. The basic dust mobilization rate for the intruder-initiated scenario is assumed to be 2.9×10^{-3} mg/m^2-sec. This is calculated by multiplying 100 hours by 0.218 mg/m^2-sec, adding this to the product of 8660 hours and 4.1×10^{-4} mg/m^2-sec, and dividing the total by 8760 hours. For the erosion-initiated scenario, the factor E is taken as the natural wind mobilization rate of 4.1×10^{-4} mg/m^2-sec.

For the erosion-initiated scenario the entire disposal site area is assumed to be exposed and A_i is calculated by dividing the volume of the waste stream being considered by the product of three factors: the volumetric disposal efficiency (assumed to 6.40 m^3/m^2 for the reference disposal facility case), the surface utilization rate (0.90), and the emplacement efficiency. The density of the soil/waste mixture is assumed to be 1.6 g/cm^3 except for those streams that are solidified using solidification scenarios A or B involving partial cement solidification. These streams are assumed to be 34% heavier.

For the wind transfer scenarios, the site selection factor (f_s) is the air-to-air transfer factor (meteorological dispersion factor X/Q - see Appendix A). For these scenarios, the number of people exposed to atmospheric releases are incorporated into the definition of the site selection factor. This results in an f_s with units of people-year/m^3.

To calculate the site selection factors, the population for the reference disposal facility (see Appendix C) is assumed to be doubled for the intruder-initiated scenario, and tripled for the erosion-initiated scenario. The number of people in each radial sector is multiplied by the corresponding atmospheric dilution factor and the results summed. The site selection factors are calculated to be 3.50×10^{-10} and 5.25×10^{-10} people-year/m^3 for the intruder- and erosion-initiated wind transfer scenarios, respectively.

3.6.2 Surface Water Scenario

Based on surface water erosion calculations (see Appendix A), the mobilization rate for the surface water scenario (i.e., the factor E in equation 3-31) is calculated to be 1.84×10^2 g/m^2-year. This factor corresponds to an annual erosion rate of about 0.82 tons/acre. Annual erosion rates vary with the soil properties, vegetation, prior erosion, topography, etc. The annual erosion rate for the Appalacian region for the past 125 million years has been calculated to be 0.75 tons/acre.(10) The other factors in the equation (i.e., A and d) remain as defined in Section 3.6.1.

The surface water site selection factor can be estimated by considering the flow rate of a nearby stream assumed to be utilized by a member of the population. In this report, the inverse of twice the value of the dilution factor Q previously utilized to determine groundwater impacts at the surface water access location (1.12×10^{-7} year/m^3 for the reference facility) will be utilized for the site selection factor. Twice the value is utilized to account for the increased flow conditions during heavy precipitation and subsequent heavy stream flow rates. The assumption of this value corresponds to dilution of the released radioactivity in a stream with a flow rate of about 10 cubic feet per second, and it is conservative since a stream with a flow rate this low is unlikely to be utilized for human consumption.

Evaluation of the surface water contamination scenarios involves consideration of certain second order effects. These effects are primarily concerned with the deposition and/or sorption of the radionuclides on soils and sediments during the surface water transport episode. Deposited and sorbed radionuclides are available for resuspension or desorption and hence represent a long-term source of radioactivity that may be further distributed. Concentration of radioactivity onto fine particles may occur, resulting in localized areas where radionuclide concentrations are higher than the initially transported material. The two separate mechanisms of deposition/resuspension and sorption/desorption are discussed below.

Deposition and/or ion-exchange by soils of mobilized radioactivity during its travel to a nearby stream has been treated in reference 13. These mechanisms are not likely to lead to significant uptake pathways to humans in addition to those pathways already considered. Most of these mechanisms take place during overland sheet-flow where conditions are more quiescent than in gullies -- i.e., the radioactivity becomes dispersed over a relatively large land area. The deposited radioactivity is probably in oxide form and unlikely to contribute to the food (soil) uptake pathway. Furthermore, any deposited or attached radioactivity undergoes a natural elimination from the land surface with a half life estimated to be about 2.5 years.(31) Moreover, the assumption of no deposition during surface water transport leads to higher concentrations in the stream receiving the discharge. This scenario is also likely to be bounded by the intruder-agriculture scenario. In any case, estimation of this component is extremely site-specific and requires a large amount of data,(23) and cannot be treated accurately in a generic study. Therefore, these mechanisms are not considered as part of the surface water scenarios.

Sediment transport in streams and possible reconcentration of the radioactivity in stream sediments are also considered in reference 13. Several mechanisms may be considered to be applicable: reversible sorption of the dissolved radioactivity by stream sediments through ion exchange, deposition of the sediments suspended in water once they reach the stream, resuspension and transport of stream sediments containing radioactivity through stream flow, and deposition of these sediments in man-made control features such as reservoirs.

A thorough evaluation of these mechanisms also requires a large amount of site specific data,(13) and does not appear to be justified in a generic analysis. Furthermore, the portion of radioactivity transported as suspended particulates is probably in the form of oxides, is unlikely to become dissolved subsequently, and, therefore, unlikely to contribute to many of the uptake pathways. The water is also likely to be filtered or stilled in ponds, eliminating most of the sediments prior to direct human consumption. Moreover, the ratio of the Cs-137 concentrations in storage pool sediments to the concentrations in upstream sediments have been observed to range from 0.92 to 4.0. These reconcentration factors are not very large when compared to bioaccumulation factors that range up to 1000 or more for several nuclides. Therefore, in this report, all the radioactivity conservatively has been assumed to be dissolved in the water accessible to the uptake pathways, and the contribution to the uptake pathways resulting from the above mechanisms have been assumed to be bounded by the scenarios considered.

3.7 Operational Accident Scenarios

There are two operational accident scenarios considered for applicability to a given stream in the impact calculations: accident-container, and accident-fire. These scenarios are described below.

3.7.1 Accident-Container Scenario

This scenario assumes that a waste container is dropped from a significant height so that the waste container breaks open and a portion of the radioactive contents of the package is released into the air where it is transported off-site and leads to subsequent human exposure. Potential releases can be modelled as a "puff", and the resulting human exposures would be over a very short time period. The potential exposures from this scenario are a strong function of the waste form - i.e., improved, less dispersible waste forms lead to lower potential releases and reduced potential human exposures. The equation describing the human exposures is as follows:

$$H = \sum_{n} f_o f_d f_w f_s \, C_w \, \text{PDCF-1} \qquad (3\text{-}27)$$

where H is the 50-year dose committment in mrem, PDCF-1 is the radionuclide specific pathway dose conversion factor discussed and presented in Section 2.3, C_w is the radionuclide concentration in the waste, and n denotes summation over all the radionuclides. The values of the barrier factors are presented below.

No reduction due to decay of the radionuclides is considered, and the time delay factor f_o is assumed to be one. Similarly, no reduction due to site design and operation has been assumed and the factor f_d has also been set equal to one.

The waste form and package factor f_w is affected by the dispersibility of the material at the time of disposal. An index that can be conveniently used to represent this property is the leachability index of the waste stream (see Section 3.3.3), which also represents the solidification scenario utilized for the waste stream. The waste form and package factor is given by the following equation:

$$f_w = 10^{(1-I9)} \times 10^{(1-I6)} \qquad (3\text{-}28)$$

The relationship $10^{(1-I9)}$ is the accessibility multiplier discussed previously. The factor $10^{(1-I6)}$ indicates the relative dispersibility of the solidified material after a container accident. The property values for this comparative dispersibility are based on consideration of comparative mechanical strengths (compressive, unnotched Izod impact, and fragmentation tests) measured for waste forms.(1) If the waste is not solidified, then I6 is assumed to be unity.

The site selection factor f_s, which is dimensionless, may be calculated by assuming that the material released is a "puff", and it stays in a puff form until it reaches the exposed individual. The following equation is utilized in this report to calculate f_s:

$$f_s = 1.56 \times 10^{-7} \times f_r \times V \times (X/Q) \qquad (3\text{-}29)$$

where 1.56×10^{-7} is the exposure duration factor, f_r is the fraction released per second, V is the volume of the container, and (X/Q) is the atmospheric dispersion factor. These parameters are considered below.

The exposure duration factor is given by the fraction of air inhaled in one intake by a man performing light activity (1.25 liters) to the annual inhalation volume (8000 m^3).(15) A man doing light activity inhales about 17 times per minute, a man resting about 12 times per minute, and a man doing heavy work about 21 times per minute.(15) If one were to assume that the puff release is longer, say one minute, then the longitudinal spread of the puff (i.e., σ_x) would be increased by a factor of 60 (resulting in a corresponding reduction in the atmospheric dispersion) while the amount of air inhaled would increase only by about 17. The assumed condition - one inhalation during the one second passage of the puff - is the most conservative case.

The source term portion of the above equation is represented by the product of f_r, the fraction released per second, and V, the volume of the container. For f_r, for the worst case, 0.1 percent of the waste is assumed to be released into air. (the case of the PuO_2 powder accident).(9) This release fraction, however, is modified by the solidification status of the waste stream (see above). The volume of the container involved in the accident, V, is assumed to be 170 ft^3 - the size of a typical resin liner.

For puff releases, the atmospheric dispersion factor (X/Q) for a ground level release and from a person standing in the centerline of the puff is given in reference 16 by the following formula:

$$(X/Q) = [\pi\sqrt{2\pi}\,\sigma_x\,\sigma_y\,\sigma_z]^{-1} \qquad (3\text{-}30)$$

where σ_x, σ_y, and σ_z are the standard deviation factors of the puff in three directions. These sigmas, in units of distance (meters), indicate the spread and dilution of the plume as a function of distance from the source. In this report, based on the average wind speed at the reference disposal facility, utilizing a value of $\sigma_x = \sigma_y = 3.61$ m, and a value of $\sigma_z = 2.2$ m,(16) yields a (X/Q) value of $4.42\text{x}10^{-3}$ sec/m^{-3}. The above assumed values yield a site selection factor of $3.323\text{x}10^{-12}$ for the reference disposal facility.

3.7.2 Accident-Fire Scenario

This scenario assumes that a fire starts in a disposal cell and lasts for approximately two hours. A portion of the radioactive material is released into the air where it is transported off site and leads to subsequent exposure to humans. Potential exposures from this scenario are a strong function of the waste form and facility design and operation. For example, a waste disposal trench in which all of the wastes are composed of compressible material (e.g., segregated disposal of compressible waste) would involve larger releases (more material to burn) than a case in which the compressible material is mixed with non-combustible waste. However, most compressible waste forms have very low levels of contamination. On the other hand, improvements in the form of the compressible material would involve lower potential releases. For example, compressible material which has been processed by incineration and solidified would involve lower potential releases than compressible waste which has been processed by compaction.

In this report, the accident-fire scenario is used to help assess the effect of improved waste forms and site operational practices on reducing the potential exposures from an accident involving an operational fire. Each waste stream or groups of waste streams may be tested separately using this scenario. The equation describing the human exposures is as follows:

$$H = \sum_{n} f_o f_d f_w f_s \, C_w \, \text{PDCF-1} \qquad (3\text{-}31)$$

where H is the 50-year dose committment in mrem, PDCF-1 is the radionuclide specific pathway dose conversion factor discussed and presented in Section 2.3, C_w is the radionuclide concentration in the waste, and n denotes summation over all the radionuclides. The values of the barrier factors are presented below.

In a manner similar to the accident-container scenario, the time delay factor f_o and the site design and operation factor f_d are assumed to be one. The waste form and package factor f_w is assumed to be equal to $0.1 \times 20^{(I4-3)}$ where I4 is the waste form flammability index (see Section 3.2.1).

The site selection factor f_s is determined by the atmospheric dispersion of the plume resulting from the accident. In this report, the plume resulting from the fire is assumed to travel in one direction and that the exposed individual is assumed to stand in the centerline of the plume for a period of time. This barrier factor is calculated by the following formula:

$$f_s = f_e \times f_r \times V \times (X/Q) \qquad (3\text{-}32)$$

where f_e is the exposure duration factor (dimensionless), f_r is the release fraction per second, V is the volume of the waste involved in the fire in units of m^3, and (X/Q) is the atmospheric dispersion factor in units of sec/m^3.

In this work, f_e is assumed to be equal to 3.63×10^{-5} based on the ratio of the air inhaled during the time period the individual is assumed to stand in the plume of the fire (10 minutes during which a man doing light activity inhales about 0.29 m^3 of air).(15) It is not reasonable to assume that an individual would stand in the centerline of the plume from the fire for more than 10 minutes. The fraction released per second, f_r, is assumed to be 1/7200 based on the assumed duration of the fire. This is equivalent to a fire duration time of 2 hours. The volume of waste involved in the accidental fire is assumed to be 100 m^3 based on an estimated annual disposal volume of 50,000 m^3, two disposal cells operating simultaneously, and one disposal cell involved in the fire. The atmospheric dispersion factor (X/Q) for an accident lasting from 0 to 8 hours is given by the equation:(17)

$$(X/Q) = \exp[-h^2/(2\sigma_z)]/[\pi u \sigma_y \sigma_z] \qquad (3\text{-}33)$$

where h is the release height (or the effective height of the plume at the fire source), u is the wind speed which is specified to be 1 m/sec assuming Pasquill Stability Class F atmospheric conditions,(17) and σ_y and σ_z are as defined previously. Utilizing values for σ_y and σ_z given in reference 17 at 100 m from the fire, and conservatively assuming ground level releases (i.e., h=0), yields a (X/Q) value of 3.62×10^{-3} and a value for the site selection factor of 1.83×10^{-9}.

3.8 Other Impact Measures

The impact measures other than individual and population exposures associated with the operation of a disposal facility include occupational exposures, land-use, disposal costs, and energy use. This section considers procedures for calculating these other measures.

3.8.1 Land-Use

Calculating the land area committed for waste disposal is a straightforward function of the total volume of the waste disposed, the waste emplacement technique (i.e., whether random, stacked, or decontainerized disposal is utilized), and the volumetric efficiency of the disposal technology considered. The volumetric efficiency is a function of site design as discussed in Section 3.2.2.

For the reference disposal facility and for disposal into a regular shallow land burial trenches (design case ID=1), the disposal volume (not the waste volume) per unit disposal cell area is 6.40 m^3/m^2. Therefore, for each 3.20 m^3 of waste that is disposed randomly, 1 m^2 of area is committed. However, this land-use rate must be divided by the surface utilization rate, calculated to be 0.90 for the reference disposal facility, since for all practical purposes, the land area between the disposal cells should be considered as committed land. Incorporating this correction results in 1 m^2 of land area committed for each 2.88 m^3 of waste disposed with random emplacement. Stacked emplacement would result in 1 m^2 of land area committed for each 4.32 m^3 of waste disposed.

Similarly, for the concrete-walled trench option (design case ID=2), the volumetric disposal efficiency is calculated to be 7.00 m^3 of disposal volume per unit disposal cell area (excluding walls of the trenches). Therefore for each 5.25 m^3 of waste disposed through stacked emplacement, 1 m^2 of disposal cell area is committed. The land-surface utilization rate in this case is calculated to be 0.35 m^2 of disposal cell area per m^2 of available land (including walls and spaces between the trenches). Therefore, the land area committed is 1 m^2 of land for each 1.84 m^3 of waste disposed.

3.8.2 Occupational Exposures

In this report, calculation of occupational exposures at the disposal facility is performed in two phases: exposures to the waste handlers during unloading and emplacement of wastes, and occupational exposures to other site personnel performing routine operational and administrative functions not directly connected with waste handling.

Occupational exposures to waste handlers are strongly dependent on the packaging of the delivered waste, the shipment mode, and the disposal procedures. Therefore, procedures for determining the occupational exposures resulting from unloading and disposal of waste are considered in the transportation impacts section of this report (see Chapter 4.0). Routine occupational exposures for personnel other than waste handlders are calculated in the next section.

3.8.3 Disposal Costs

Other impact measures - disposal costs, routine occupational exposures to people other than waste handlers, and energy use - are closely interrelated and are dependent on the waste volume disposed, the land-use rate, operational practices, etc. These three measures are considered in this section.

All the basic rates (rates per unit volume or area) associated with costs (prior to multipliers to account for the cost of money, profit, inflation, etc. - see below), energy use, and routine occupational exposures at a disposal facility have been calculated in Appendices E and F of reference 3. These basic unit rates are summarized in Table 3-9.

TABLE 3-9 . Unit Rates for Impact Measures

Activity	Cost (thousand 1980 $)	Occupational[a] Exposure (person-mrem)	Energy Use (thousand gallons)	Units[b]
Capital				
Reference Base Case	7452	--	212	Lump Sum
Additive Alternatives[c]				
Walled Trench	594	--	--	" "
Stacking	226	--	--	" "
Segregation	1	--	--	" "
Layering	132	--	--	" "
Uncontainerized Disposal	924	--	--	" "
Hot Waste Facility	260	--	--	" "
Grouting	55	--	--	" "
Intruder Barrier	281	--	--	" "
Extreme Stabilization	10	--	--	" "
Operational				
Reference Base Case				
Trench (-Cover)	2341	300	200	Disposal Vol.
Regular Cover	1420	2400	100	Disposal Area
Other Costs	63696	1000	200	Lump Sum
Additive Alternatives[c]				
Walled Trench	74438	700	300	Disposal Vol.
Stacking	12758	100	100	Waste Volume
Segregation	3888	100	30	" "
Layering	15400	-100	30	Layered Vol.
Decontainerized Disposal	48975	400	100	Decont. Vol.
Hot Waste Facility	176979	-200	450	Hot Waste Vol.
Grouting	72405	2550	800	Grout Volume
Sand Backfill	2370	--	185	Sand Volume
Cover Options				
Thick	15524	2400	150	Disposal Area
Intruder Barrier	103854	2400	300	" "
Moderate Stabilization	3465	4800	300	" "
Extreme Stabilization	33345	4800	600	" "

TABLE 3-9 (continued)

Activity	Cost (thousand 1980 $)	Occupational[a] Exposure (person-mrem)	Energy Use (thousand gallons)	Units[b]
Post-Operational				
Closure Period				
Regular Closure	1010	500[d]	15	Lump Sum
Extensive Closure	3025	1000	60	" "
Institutional Period[e]				
Low Care Level				
Years 1-10	150	--	2	Per Year
Years 11-25	63	--	2	" "
Years 26-100	51	--	2	" "
Medium Care Level				
Years 1-10	303	--	6	" "
Years 11-25	150	--	6	" "
Years 26-100	63	--	6	" "
High Care Level				
Years 1-10	440[f]	--	10	" "
Years 11-25	303	--	10	" "
Years 26-100	150	--	10	" "

(a) Occupational exposures associated with operations other than waste unloading and disposal.

(b) Lump sum items are assumed to be independent of the waste volume since increased volume reduction implies higher activity wastes requiring more attention and effort; disposal volume dependency is for 1 million m^3 of disposal (not waste) volume; layered volume dependency is for 1 million m^3 of layered waste disposed; analogously, decontainerized, hot waste, grout, and sand volume dependencies are for 1 million m^3 of waste/material of concern; disposal area dependency is for 1 million m^2 of trench cover area.

(c) All these rates for alternatives are incremental rates in addition to the rates given for the reference system.

(d) Regular closure assumed to last 2 years; extensive closure is assumed to last four years. Both cases assume 5000 person-hours of field work per year in an average radiation field of 0.05 mR/hr.

(e) These costs are basic costs not considering inflation or interest. Details for complete calculation of the institutional period costs, including consideration of inflation and interest, can be found in Appendix Q of reference 3. The formulae given in that appendix are incorporated into the cost calculation procedure.

(f) To this cost, a contingency cost is added which depends on the soil conditions: $367,000 for medium-permeability soils, $168,000 for high-permeability soils, and, $1,007,000 for low-permeability soils (see Appendix Q of reference 3).

The unit rates presented in Table 3-9 are utilized in a computer program (OPTIONS) that calculates the impact measures. Depending on the disposal facility design option selected, the status of each waste stream, Ill, is determined utilizing procedures outlined in Section 3.4. Then, the volumes of waste that are unacceptable for near-surface disposal, waste disposed of through regular means, waste disposed through layered option (if any), and waste emplaced in a hot waste facility (if any) are determined. These waste volumes together with the selected emplacement procedure give the respective disposal volume required, and the disposal volumes together with the volume utilization rates give the respective areas involved. Then, these areas are utilized to calculate costs for design options such as the thickness of disposal cell covers. These unit rates are briefly discussed below.

Costs associated with the operational life of the disposal facility are divided into capital costs and operating costs as discussed in Appendix Q of reference 3. Base case capital costs are calculated from the information given in Appendix Q (for the reference disposal facility costs) and includes consideration of environmental investigations, licensing costs, land purchase cost, road construction, building construction, and peripheral system installation. Additional capital costs associated with implementation of a specific design option are quantified in Appendix F of reference 3 and are added appropriately during the calculation.

The options considered during the operational life are divided into two groups: the reference system, and the design options which are subdivided into volume dependent options and area dependent options. For calculational convenience, these unit rates are converted to disposal volume rates since different emplacement procedures are applicable. The items considered under "other" rates include payroll, administration, equipment, etc. It is assumed that changing disposal waste volumes due to processing will not alter the rates given as "lump sum" significantly, increased volume reduction implies higher activity wastes resulting in increased effort.

The second group of options (termed additive alternatives in Table 3-9) result from the application of the available design options (ID, IS, IE, IL, IH, IG) discussed in Section 3.2 in a straightforward manner. These rates are also estimated from a wider range of design and technology options considered in reference 3. The rates given are normalized, however, to one-million m^3 of waste volume for calculational convenience. Similarly, grouting option rates are for one-million m^3 of grout injected since the option may be exercised with either random or stacked disposal, etc. One consequence of the application of the hot waste facility option is that the total routine occupational exposures are estimated to go down as a result of increased shielding afforded by the special facility, this effect is expressed by giving a negative occupational exposure to the hot waste facility. The third group of operational options result from the application of cover related options (IC, IX) discussed in Section 3.1. These options are area dependent. For calculational convenience they also have been normalized to one-million m^2.

All these options are additive. For example, the preoperational and operational costs resulting from disposal of 900,000 m^3 of waste (all found acceptable for near-surface disposal) in the reference facility with an assumed volume efficiency of 5 m^3/m^2, with stacked emplacement (0.75), with grouting, with thick cover, and with extreme stabilization are tabulated in Table 3-10. Occupational exposures and energy use are calculated in a similar manner.

These costs, however, must be multiplied with two conversion factors to account for the cost of money, inflation and other financial considerations. The formulae for these multipliers are presented below. A more detailed explanation of the derivation of these multipliers can be found in Appendix Q of reference 3.

TABLE 3-10 . Illustrative Calculation

Assumptions: 900,000 m^3 of waste
stacked, grouted, thick cover,
extreme stabilization,
disposal efficiency of 5 m^3/m^2

Disposal Volume = 900,000/0.75 = 1,200,000 m^3
Empty Disposal Space = 1,200,000x(1-0.75) = 300,000 m^3
Disposal Area = 1,200,000/5 = 240,000 m^2

Capital Costs	
Reference System	$ 7,452,000
Stacking	226,000
Grouting	55,000
Total Capital :	$ 7,733,000

Operational Costs	
Reference System	
Trench Construction	$ 2,810,000
Regular Cover	341,000
Other Costs	63,696,000
Additive Alternatives	
Stacking Option	11,482,200
Grouting Option	21,721,500
Thick Cover	3,725,800
Extreme Stabilization	8,002,800
Total Operations :	$111,779,300

For capital costs, the following items are applicable:

Item	Factor
Indirect Costs	1.73
Fixed Charge	5.00
Profit	1.20

Indirect costs result from interest during construction, contingency, and other costs such as miscellaneous overhead expenses, insurance, sales tax, etc. The fixed charge results from an assumed 25% charge on capital over the 20 year operating life of the facility. These three items result in a multiplier of 10.38 for the pre-operational capital costs. For the operational costs, the following items are applicable:

Item	Factor
Contingency	1.30
Profit	1.20

This results in a multiplier of 1.56 for the operational costs. Using these multipliers with the pre-operational capital cost of $7,733,000, and the operational cost of $111,779,300 yields a total preoperational and operational cost of about $254,644,000 in 1980 dollars.

Post-operational costs (composed of closure costs and long-term care costs) are calculated using the following two equations. For the closure costs, the following equation is applied:

$$\text{Closure Costs} = C_{80} \times L \times (1+j)^{L} \times \quad f + \frac{i}{(1+i)^{L} - 1} \qquad (3\text{-}34)$$

where C_{80} is the closure costs presented in Table 3-9, L is the facility life in years, f is an annual fee for a surety bond which assures availability of closure funds (1.5% is used in this report), and j is the inflation rate (9% is used in this work). For long-term care costs, the following equation is applicable:

$$\text{LTC Cost} = PV_{80} \quad \frac{L \times (1+j)^M \times i}{[(1+i)^L - 1] \times (1+i)^C} \qquad (3\text{-}35)$$

where LTC stands for long-term care, L is the site operational life in years, C is the closure period in years, M is L+C, i is the interest rate (assumed to be 10% in this report), j is the inflation rate, and PV_{80} is given by the following equation:

$$PV_{80} = C_a \sum_{n=1}^{10} R^n + C_b \sum_{n=11}^{25} R^n + C_c \sum_{n=26}^{100} R^n \qquad (3\text{-}36)$$

where R is the ratio (1+j)/(1+i). The parameters C_a, C_b, and C_c are the annual costs given in Table 3-9 for the long-term care costs during the years 0-10, 11-25, and 26-100, respectively. The cost rate C_a may include a contingency cost for a high level of long-term care as explained in Table 3-9.

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4.0 TRANSPORTATION IMPACTS

This chapter discusses the calculational procedures used to determine impacts associated with transportation of waste to the disposal facility. The impact measures developed in this report include: cost; occupational exposures associated with loading, transportation, and unloading of the waste; population exposures associated with transportation; and energy use. Section 4.1 presents the packaging and shipping assumptions utilized in the calculations. Transportation costs and other impact measures are presented in Sections 4.2 and 4.3, respectively.

4.1 Packaging and Shipping Assumptions

Potential impacts (e.g., occupational exposures, population exposures, and costs) incurred during transportation of wastes to disposal facilities and during subsequent unloading and emplacement operations are influenced by a number of interrelated factors. These interrelated factors increase the complexity of the impacts analyses and arise from the greatly variable nature of LLW and LLW transportation. For example, LLW can be generated in a great variety of forms and can range from wastes having very low to moderately high radioactivity concentration levels. In addition, a range of waste container types and sizes are presently available and in use.

For the purposes of this report, some simplifying assumptions regarding waste packaging and transportation are made based upon past experience. These assumptions include those in the following areas:

(1) The degree of care required for waste handling and transportation (package surface radiation levels);
(2) Container sizes and types; and
(3) The shipment mode (vehicles and overpacks used).

Additional information on surface radiation levels, packaging parameters, and mode of shipment regarding these simplifying assumptions is provided below.

4.1.1 Surface Radiation Levels

Radiation levels at the waste package surfaces affect the care required in handling of wastes and the shielding that may be required during transportation. Depending on the package size involved and the total activity content of each package, different waste packages have different surface radiation readings. For the purposes of this report, the waste streams are generically classified into three categories according to the level of care required to handle each waste stream:

(1) Regular care
(2) Special care
(3) Extreme care

Package sizes and packaging procedures are instrumental in determining the self-shielding afforded by some of the waste packages. However, there can be significant variations in the level of care required for each package due to variations in the specific activities of the wastes within a given stream. For this analysis, the level of care is assumed to be independent of waste package shape and volume. The level of care is assumed to depend only on the total specific activity contained in the waste package and the presence or absence of radionuclides emitting high-energy gamma rays.

Each waste stream is denoted by an index representing the type of activity with regard to high-energy gamma emitting radionuclides. Waste streams containing significant quantities of fission products (most notable being Co-60, Nb-94, and Cs-137) are denoted as the first category. Waste streams containing very little high-energy gamma emitters (and consequently all requiring a "regular" level of care)

are denoted as the third category. Other streams in between these two are denoted as the second category:

Category 1 : Fission product type wastes
Category 2 : Other type wastes
Category 3 : All regular care wastes

In addition to these categories, the specific activity, and therefore the required level of care, for a given waste stream varies significantly. For example, surface radiation readings of similarly-sized LWR resin packages varying over two or three orders of magnitude have been observed.(1) To account for this normal variation, Table 4-1 is used to estimate the fraction of each waste stream that requires a specific level of care based on the total specific activity of the waste stream.

The values in this table are estimated based on standard health-physics "rules of thumb" calculations for determining the surface radiation level of a waste package, e.g., the 6CEn formula.(2) For example, for waste in Category 1 with about 2 Ci/m^3 of activity, 20% of the waste volume is assumed to require regular care, 60% of the waste volume is assumed to require special care, and the remaining 20% is assumed to require extreme care. According to the 6CEn formula, assuming that all the radioacivity is Co-60 and the waste package is a 55-gallon drum, this waste may have a radiation reading of about 6 R/hour. For waste in Category 2 with about 0.2 Ci/m^3 of activity, 80% of the volume is assumed to require regular care, and the remaining 20% is assumed to require special care. All wastes in Category 3 are assumed to require regular care.

After determining the fraction of volume in each stream that requires a specific level of care, this waste is assumed to be packaged and shipped. The packaging and shipping assumptions for these fractions are detailed below.

TABLE 4-1 . Distribution Between Care Level Required with Type and Specific Activity of Waste

Total Specific Activity (Ci/m^3)			Percent Waste Stream Volume in Each Handling Category		
Type 1	Type 2	Type 3	Regular	Special	Extreme
<0.01	<0.1	All	100	--	--
.01-.1	.1-1		80	20	--
.1-1	1-10		40	50	10
1-10	>10		20	60	20
10-100			10	50	40
>100			--	20	80

4.1.2 Packaging Parameters

There are many different types of packaging currently utilized for shipment and disposal of LLW.(3,4) These packages include wooden boxes of various sizes ranging from 10 ft^3 to 248 ft^3, 55 gallon drums, and liners (usually carbon steel) of various sizes ranging from 16 ft^3 to 200 ft^3 which fit into transport casks. In this report, for the generic type of analyses required for the transportation and disposal impacts, these packages were generalized into five different categories:

(1) Large wooden boxes - 128 ft^3
(2) Small wooden boxes - 16 ft^3
(3) 55-gallon drums - 7.5 ft^3
(4) Small liners - 50 ft^3
(5) Large liners - 170 ft^3

The primary rationale for selecting these sizes is that they appear to the most widely used sizes, and may be used to represent an average of other packages. For example, the 128 ft^3 box is the most commonly used (4'x4'x8') size to ship low specific activity (LSA) waste, the 170 ft^3 liner is the commonly available 6'x6' right-circular cylindrical resin tank, etc.

During the transportation analysis, for regular- and special-care wastes, all five methods of packaging are assumed to be acceptable. The high-activity of extreme-care wastes renders the use of boxes for packaging unacceptably inconvenient, therefore, all waste that is classified "extreme care" has been assumed to be packaged in either drums or liners which are remotely manipulated for loading and off-loading.

The distribution of these package types for each waste stream have been assumed using available shipping and survey data,(3-6) and are presented in Table 4-2.

TABLE 4-2 . Packaging of LLW for Waste Spectrum 1 (percent of volume packed in containers)

Waste Stream	Large Boxes	Small Boxes	55-g Drums	Small Liners	Large Liners
LWR Process Waste Group	--	--	69	15	16
Trash Group (except P-&B-NCTRASH)	23	8	69	--	--
P- & B-NCTRASH	--	--	100	--	--
Low Specific Activity Waste Group (except F- & U-PROCESS)	--	2.5	97.5	--	--
F- & U-PROCESS	--	--	100	--	--
Special Waste Group	--	--	100	--	--

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* Other distributions depending on the spectrum may be imposed on the individual waste streams.

4.1.3 Mode of Shipment

Similar to the numerous different types of available waste packages, there may exist many different shipment modes ranging from rail and barge transport to truck transport. Many different types of overpacks may be used depending on the handling and shielding requirements for individual waste packages.(3,4)

In this report, only truck transport is considered because trucks are the most commonly used mode of transportation and truck transport is radiologically the most conservative case. Vehicles and overpacks utilized in truck shipments depend on package sizes as well as package shielding requirements. In this report, six different types of transport vehicles and overpacks are assumed:

(1) Vans
(2) Flatbed trailers
(3) Shielded trailers
(4) Large shielded casks
(5) Small shielded casks
(6) 1-drum shielded casks

Large casks are used for transporting either large liners or fourteen 55-gallon drums, while small casks are used for transporting either small liners or six 55-gallon drums. These casks are transported to the disposal facility via flatbed trailers.

The use of particular types of vehicles and overpacks is strongly influenced by the level of care required for safe waste handling and transport of the waste packages. Vans are assumed to be suitable for all types of containers in the regular care category, with the exception of large liners which require casks. In addition, flatbed trailers are assumed to be used only for large boxes of regular-care wastes. Shielded trailers are assumed to be required for large and small boxes and drums of special-care wastes. Some of these small boxes and drums, as well as large and small liners are assumed to require casks. Casks are assumed to be the only acceptable mode of transport for extreme-care wastes.

The percentage use of different vehicles and overpacks for each container have been estimated considering records of waste shipments delivered to the Maxey Flats Disposal Facility.(1) A tabular listing of the basic assumptions made for the transportation of wastes is presented in Table 4-3. Extreme-care liner shipments have been assumed to be "overweight" shipments since these require significant shielding for transportation purposes. These are also designated in Table 4-3.(1,5)

4.2 Costs

Transportation costs include a mileage charge (including a fuel surcharge), a cask use charge (rental), and an overweight shipment transportation charge.

The mileage charge is calculated by estimating the total shipment miles required (including return trip mileage for casks), using an assumed average distance per one-way shipment. The basic transportation charge depends on the one-way distance, and is assumed according to the following table:(8)

One-Way Distance	One-Way ($/mile)	Round Trip ($/mile)
< 400 miles	1.69	1.25
400-1000 miles	1.47	1.14
> 1000 miles	1.17	1.08

Added charges, which become significant for extreme-care shipments, include a fuel surcharge (15% of the basic cost) and an overweight charge. The amount of the overweight charge depends on the maximum gross vehicle weight (GVW) allowed in states through which the shipment passes. Any overweight condition up to 85,000 lbs. is charged at

TABLE 4-3 : Packaging and Shipment Mode Parameters

Care Level and Container	Overpack[a]	Per Shipment		Man-Minutes for Disposal Per Container	
		Pieces	Percent Volume	Random	Stacked
Regular Care					
Large Box	Van	3	24	200	240
	FB	4	76	74	120
Small Box	Van	36	100	16	24
Drum	Van	70	100	6	24
Small Liner	Van	11	100	136	165
Large Liner	LC	1	100	1200	1440
Special Care					
Large Box	ST	3	100	300	360
Small Box	ST	36	96	26	39
	LC	6	4	250	300
Drum	ST	70	48	10	24
	LC	14	51	86	175
	SC	6	1	200	312
Small Liner	SC	2	100	600	720
Large Liner	LC	1	100	1200	1440
Extreme Care					
Drum	SC	6	51	200	312
	1D	1	49	600	720
Small Liner	SC[b]	2	100	600	720
Large Liner	LC[b]	1	100	1500	1800

(a) FB = flatbed trailer ; ST = shielded trailer; LC = Large shielded Cask; SC = Small Shielded Cask; 1D = 1-drum shielded cask.

(b) These shipments are estimated to be overweight.

$0.21/mile plus the permit charges for each state (about $100 per 600 miles). A GVW of over 85,000 lbs. is additionally charged $0.005 per mile per hundred pounds (cwt) over this limit. For example, for a shipment of 96,000 lbs., which is a minimum for an extreme-care cask, the charges for a one-way trip of 600 miles would be as follows:

Basic cost @ $1.14/mile	$1,368.00
Fuel surcharge @ 15% of charge	205.00
Overweight charge @ $0.21/mile	126.00
Overweight surcharge @ $0.005/cwt/mile	330.00
Five overweight permits @ $20.00/state	100.00
Total :	$2,129.00
Per Mile :	$ 3.55

The cask use charge calculation assumes an average turnaround time of 4 days. Cask rental rates vary depending on the size and weight of the cask required. They average $250/day for shielded casks enclosing high activity LLW, and range down to $110/day for an unshielded 120 cubic feet capacity cask.(9) The rental rates also vary with the specific type of nuclear material the cask is licensed to carry and the accompanying performance standards the cask must satisfy to accommodate the various types of nuclear materials. The calculated results for the additional factors can then be summed to determine the total transportation cost for the waste.

4.3 Other Impacts

In addition to costs, three other impact measures resulting from LLW transportation are calculated in this report: energy use, occupational exposures, and population exposures. These impacts are reviewed in this section.

The energy use is calculated based on the total shipment miles, including empty cask return trips, and an average fuel consumption rate of 6 miles/gallon.

The occupational and population exposures incurred during transportation are calculated based on total loaded miles and the number of loaded shipments. The concept of loaded miles and shipments allows to be eliminated from consideration those miles in which the vehicle is empty because it is on a return trip.

Occupational and population exposures are calculated separately for those resulting during transit, and those resulting from stopovers during the trip. The occupational exposure during stopovers is estimated by assuming two drivers. Each inspect the overpack for 3 minutes (10 mR/hr radiation field at the surface of the overpack), and walk around the overpack for 30 minutes (1 mR/hr radiation field at about 3 ft). This yields 2 person-mrem per stop for each shipment. For population exposure during stopovers, the following equation can be utilized:(11)

$$D = 2\pi K\ d\ T\ E_1(\mu r) \tag{4-1}$$

where

D = Population dose in person-mrem
K = Source Density = 1000 $\mathrm{mR\text{-}ft^2/hr}$
d = Population Density = 10000 $\mathrm{people/mile^2}$
T = Duration of Exposure = 2 hours
E_1 = Exponential Integral,
μ = Linear Absorption Coefficient of Air = 0.003 $\mathrm{ft^{-1}}$.
r = Lower Distance for Population = 100 ft.

The source density K is based on an assumed maximum allowable exposure rate of 10 mR/hr at contact with the overpack(10,12) (assumed to be 10 ft from the center of the waste package) extrapolated to the center of the package using the $(1/r^2)$ radiation attenuation principle:

$$\text{Exposure at 10 ft from the center} = 10\ \mathrm{mR/hr} = K/(10\ \mathrm{ft})^2$$

The assumed population density of 10,000 people/mile^2 is conservative considering that the average U.S. population density is estimated to be around 300 to 400 people per square mile. This relatively high number is assumed since truck stops are likely to be near small population centers. The linear absorption coefficient of air is assumed based on the energetic gammas expected to be present in LLW (i.e., Co-60, Nb-94, and Cs-137 gamma radiations). This calculation also yields about 2 person-millirem per stop for each shipment. These doses in units of person-millirem are summarized below.

To estimate the occupational and population exposures during transit, the values per shipment-mile given in WASH-1238 are utilized.(10) These exposure rates are summarized below.

	Population Doses (person-mrem)	Occupational Doses (person-mrem)
During Transit Per Shipment Mile	0.018	0.02
During Stopover Per Shipment	2.0	2.0

Occupational exposures resulting from the loading of the waste packages are also included in the transportation occupational exposures. The occupational exposures resulting from waste unloading and emplacement at the disposal facility are considered in Section 4.4, although they are also partially based on the assumptions presented in this section.

The occupational exposures are calculated based on two factors: the man-minutes required to load each container, and the radiation field associated with each type of container handling. The man-minutes for stacked disposal shown in Table 4-3 are assumed to be applicable for loading of the wastes. The radiation levels associated with the handling environment (not the package surface radiation levels) for each level of care were assumed to be as follows:

Level of Care	Radiation Level (μR/hr)
Regular	750
Special	1800
Extreme	2200

The product of these two factors for each combination of care level, package, and shipment mode have been calculated and are presented in Table 4-4. This table is utilized to compute transportation occupational exposures received during waste loading operations.

4.4 Occupational Exposures to Waste Handlers

The calculation of these exposures is straightforward based on estimates of personnel time required for unloading and disposal of the wastes. These estimates are presented in Table 4-3. Other parameters necessary for the computations are the radiation fields associated with the working environment. These fields are assumed to be a function of the care level of the package and whether the disposal is random or stacked. The following table presents these assumptions:

Level of Care	Radiation Level (μR/hr) Random	Radiation Level (μR/hr) Stacked
Regular	500	750
Special	1200	1800
Extreme	2200	2200

Impacts calculated from these relationships are added to the disposal facility occupational exposures calculated in Section 3.8.3 for disposal facility personnel other than waste handlers.

Decontainerized disposal of waste is assumed to require twice the time needed for stacked handling for those packages that are to be disposed in this manner (i.e., unstable wastes denoted by I8 = 0 -- see Chapter 3.0).

TABLE 4-4. Unit Occupational Exposures During Loading
(person-millirem per container)[a]

	Regular Care		Special Care		Extreme Care	
Container	Overpack	Exposure	Overpack	Exposure	Overpack	Exposure
Large Boxes	Van	3.0	ST	10.8		
	FB	1.5				
Small Boxes	Van	0.3	ST	1.17		
			LC	9.0		
Drums	Van	0.3	ST	0.72	SC	11.44
			LC	5.25	1D	26.40
			SC	9.36		
Small Liners	Van	2.06	SC	21.6	SC	26.40
Large Liners	LC	18.0	LC	43.2	LC	80.67

(a) FB = flatbed trailer ; ST = shielded trailer; LC = Large Shielded Cask; SC = Small Shielded Cask; 1D = 1-drum Shielded Cask.

REFERENCES FOR CHAPTER 4.0

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11. Dames & Moore, "Study of the Shipment of Spent Fuel from the Shoreham Nuclear Power Station to the Reprocessing Plant," Prepared for Long Island Lighting Co., Inc., June 1975.

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5.0 WASTE PROCESSING IMPACTS

This chapter discusses the calculational procedures utilized to determine the impact measures associated with the processing of the waste streams considered in this report (see Chapter 3.0). These impact measures include population exposures, occupational exposures, costs, and energy use. The processing options being considered in this report, and the derivation of the unit rates for costs, person-hours, and energy use for these processing options are presented in reference 1. Based on this information and using an additional waste stream index, denoted by I10, the processing impacts are calculated for respective cases utilizing the assumptions and procedures presented in this section.

5.1 Waste Processing Index

The variations in the processing technologies applied to a given stream, which affect the calculation of the impact measures, include the volume reduction process type, the volume increase process type, the location of the processing, and the environment in which the processing takes place. For calculational convenience, the waste processing option applicable to each waste stream for each waste spectrum has been digitized and is called the waste processing index, denoted by I10 (see Chapter 3.0 for other waste form behavior indices).

The index I10 is a four digit number with each digit denoting a specific procedure for calculation of the impact measures. These digits cumulatively correspond to a specific case. The meaning of the digits that make up the processing index is presented in Table 5-1. The processing indices applied to each waste stream for each spectrum are presented in Table 5-2.

The impact measures calculated represent impacts in addition to those associated with Spectrum 1 with the exception of a few streams for

TABLE 5-1 . Waste Processing Index - I10

	Value	Meaning
First Digit - IPR	0	No Volume Reduction
	1	Regular Compaction
	2	Improved Compaction
	3	Hydraulic Press
	4	Evaporation
	5	Pathological Incineration
	6	Small Calciner
	7	Large Calciner
Second Digit - ISL	0	No Solidification
	1	Solidification Scenario A
	2	Solidification Scenario B
	3	Solidification Scenario C
Third Digit - ILC	0	No Processing
	1	Processing at the Generator
	2	Processing at the Disposal Site
Fourth Digit - IEN	0	No Incineration
	1	Urban Environment
	2	Rural Environment

TABLE 5-2 . Processing Index (I10) Breakdown

	Waste Spectrum 1				Waste Spectrum 2				Waste Spectrum 3				Waste Spectrum 4			
	IPR	ISL	ILC	IEN	IPR	ISL	ILC	IEN	IPR	ISL	ILC	IEN	IPR	ISL	ILC	IEN
P-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
P-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-FCARTRG	0	1	1	0	0	2	1	0	0	3	1	0	0	3	1	0
B-IXRESIN	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
B-CONCLIQ	0	1	1	0	4	2	1	0	4	3	1	0	6	3	1	2
B-FSLUDGE	0	0	1	0	0	2	1	0	0	3	1	0	6	3	1	2
P-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
P-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
B-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
B-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0
F-COTRASH	0	0	0	0	1	0	1	0	6	3	1	2	6	3	1	2
F-NCTRASH	0	0	0	0	0	0	0	0	0	0	0	0	3	0	2	0
I-COTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
I+COTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-SSTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+SSTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
N-LOTRASH	0	0	0	0	1	0	1	0	5	3	1	1	5	3	1	1
N+LOTRASH	0	0	0	0	2	0	2	0	7	3	2	2	7	3	2	2
F-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
U-PROCESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I-LIQSCVL	0	0	1	0	1	0	1	0	5	3	1	1	5	3	1	1
I+LIQSCVL	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-ABSLIQD	0	0	1	0	0	2	1	0	0	3	1	0	5	3	1	1
I+ABSLIQD	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
I-BIOWAST	0	0	1	0	0	0	1	0	5	3	1	1	5	3	1	1
I+BIOWAST	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0
N-SSWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-LOWASTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-NFRCOMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L-DECONRS	0	3	1	0	0	3	1	0	6	3	1	2	6	3	1	2
N-ISOPROD	0	2	1	0	0	3	1	0	0	3	1	0	0	3	1	0
N-HIGHACT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TRITIUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-SOURCES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-TARGETS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

which waste processing does occur in Spectrum 1, the streams which are processed in Spectrum 1 are LWR concentrated liquids, and institutional wastes. For the other streams, the processing indices for Spectrum 1 are utilized in the calculation of the impact measures for the other waste spectra.

5.2 Population Exposures

For the purposes of calculation of population exposures in this report, only incineration is assumed to result in significant atmospheric releases to the environment. The fraction of the radioactivity released depends on the type of incinerator, the controls on the off-gas system, and the radionuclide.

In this report, the fractions of the total input activity released to the atmosphere are assumed to be the following:(1)

	Release Fraction and Incinerator Type	
Nuclide	Pathological	Calciner
H-3	0.90	0.90
C-14	0.75	0.25
Tc-99	0.01	0.001
I-129	0.01	0.001
All Others	2.5×10^{-4}	2.5×10^{-6}

In this table, a calciner/incinerator is generally assumed to have better off-gas controls than a pathological incinerator. Most of the incinerated tritium is released as water vapor. Although some of the tritiated water vapor may deposit in very close vicinity of the release point due to condensation,(2) this effect is conservatively not considered in this report. Carbon-14 is usually released as tagged CO, CO$_2$ and other combustion gases. Technicium-99 and I-129 are usually considered as semi-volatile nuclides that are harder to control than particulates. All other radionuclides are assumed to be particulates, and particulate release fractions are applied. These fractions are also used in modifying the waste concentrations for tritium and carbon-14. Release fractions for other radionuclides are conservatively assumed not to affect the concentrations of the final product.

The final assumptions on population exposure calculations involve (1) the environment that is affected by the processing, and (2) the pathway dose conversion factors used.

It is assumed that institutional facilities are in an urban environment and all other facilities (including the disposal site) are in a "rural" environment. Correspondingly, a site selection factor (sum of the products of the atmospheric diffusion factor -- see Appendix A -- and the number of people affected in each corresponding radial distance -- see Appendix C) of 1.75×10^{-10} person-year/m^3 is applied to a rural environment, and ten times this value, i.e., 1.75×10^{-9} person-year/m^3, is applied to an urban environment.*

The pathway dose conversion factor used in calculating the population doses are those applicable to the erosion-air transport scenario, -- i.e., PDCF-8 presented in Table 2-11.

5.3 Other Impacts

Other impacts are calculated based on the unit rates (cost, labor-hours, and energy use) that have been assumed based upon information presented in references 3 through 6 for selected waste processing options. These unit rates are summarized in Table 5-3 and are discussed below.

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* In Section 3.6.1 a value of 3.50×10^{-10} person-year/m^3 is estimated to be applicable to a disposal site 100 years after closure, this value is twice the value obtained from application of the population distribution for the reference disposal facility presented in Appendix C.

TABLE 5-3 . Summary of Processing Unit Impact Rates

Process	Cost (1980 $)	Labor (hours)	Energy (g of fuel)	Units
Compaction				
Regular	335	15	4.6	Per m^3 of Input
Improved	503	15	4.6	
Hydraulic Press	1006	15	4.6	
Evaporation	690	4.42	56.3	Per m^3 of Input
Incineration				
Pathological	2060	8	116	Per m^3 of Input
Calciner (small)	1938	6.12	129	
Calciner (large)	1039	5.35	72	
Solidification				
Scenario A	1282	24	40	Per m^3 of Output
Scenario B	1873	24	40	
Scenario C	2445	24	40	

In this report, the energy use impact measure is expressed in units of gallons of fuel, and the factors utilized in the calculations to correct from electrical energy and thermal energy to gallons of fuel are 40.6 kW-hr per gallon of fuel and 138,690 BTU per gallon of fuel, respectively.(5) Another assumption involving energy use is that 10 percent of the first year capital cost (in 1980 dollars) has been assumed to be attributable to fuel use at $1/gallon.

Occupational exposures resulting from waste processing occur primarily as a result of repair and maintenance activities on the waste processing equipment, however, there is no reliable way to estimate the exposures resulting from equipment repair and maintenance in a generic manner. This is due to the wide variations in the design of processing equipment, as well as variations in the effectiveness of administrative controls at waste generator facilities.

In this report, the occupational exposures have been assumed to be independent of the waste concentrations, and they are calculated as the product of the person-hours required to process a unit volume of waste and the radiation field associated with the general work environment. The person-hours required to process a unit volume of waste is substantially more than the repair work requirements; however, the volume of waste processed may be assumed to be proportional to the repair work required. The radiation field associated with the general work environment is likely to be less than the radiation fields associated with repair work. However, the radiation field values assumed in this report may be taken to represent an average of those for repairing and maintaining the equipment, and those for routine processing.

In this work, all LWR waste processing is assumed to take place in a radiation field of 0.5 mR/hour, and all other waste processing is assumed to take place in a radiation field of 0.1 mR/hour. Based on these assumed radiation fields and the labor hours required to process unit volumes of waste (presented below), it is straightforward to calculate the occupational exposures.

Another factor which affects the impact measures and which has been considered in the impact calculations is the "savings" resulting from the change in waste volume. This is represented by differential costs in packaging and storage, differential savings in occupational exposures resulting from handling less waste in storage, and differential savings in energy. These unit rates are assumed based on information presented in reference 3. The unit "savings" applied to each waste stream are assumed to be \$210, 4 person hours, and 0.4 gallons of fuel per unit volume (m^3). These unit rates are applied to the difference between the pre-processing waste stream volume and the volume of the waste stream after processing. If the waste processing results in additional volumes of waste (e.g., solidification), then these savings become additional impacts.

The unit rates for costs, energy use, and labor-hours assumed for the processes considered in this report - compaction, evaporation, incineration, and solidification - are presented below.

The unit rates for a compactor/shredder processing 7360 ft^3 of trash per year are presented in Table 5-4.(3,4) Based on the unit rates given in Table 5-4, and the description of the equipment provided in reference 3, an improved compactor is estimated to cost 50 percent more while requiring the same labor hours and energy use. The hydraulic press unit rates have been estimated to cost approximately twice as much as the improved compactor while requiring the same labor-hours and energy use.

The estimates presented in reference 3 for an evaporator/crystallizer annually processing 15,963 ft^3 of waste have been used to estimate the unit rates for evaporation. These rates are summarized in Table 5-5.

TABLE 5-4 . Compaction Unit Rates[a]

Item	(1980 $)[b]
Total Capital Cost[c]	$164,428
First Year Cost	5,481
Annual Operating Costs[d]	
Labor - 3120 person-hours	56,160
Maintenance and Consumables	6,600
Utilities 16,390 kW-hr	1,491
Total :	$ 69,732

Unit Rates[e] per m^3

Costs = $69732 \times 4.8\text{x}10^{-3}$ = $ 335

Labor = $3120 \times 4.8\text{x}10^{-3}$ = 15 hours

Energy = $(548+16390/40.6) \times 4.8\text{x}10^{-3}$ = 4.6 Gallons

---

(a) For a compactor processing 7360 ft^3 of waste annually.

(b) 1984 costs given in reference 3 are divided by $(1.13)^2$ given in that reference to get 1980 costs.

(c) Source : Reference 3, Table K.56. Capital costs include equipment, piping and instrumentation, electrical, and building (12'x12'x16').

(d) Source : Reference 3, Table K.57, and Reference 4.

(e) $4.80\text{x}10^{-3} = 35.315\ ft^3/m^3\ /\ 7360\ ft^3$.

TABLE 5-5 . Evaporator Unit Rates[a]

Item	(1980 $)[b]
Total Capital Cost[c]	$4,775,347
First Year Cost	159,179
Annual Operating Costs[d]	
Labor - 2000 person-hours	36,000
Maintenance and Consumables	104,500
Utilities 3,725 kW-hr	339
$1,308 \times 10^6$ BTU	11,667
	Total : $311,685

Unit Rates[e] per m^3

Costs = $311685 \times 2.212 \times 10^{-3}$ = $ 690

Labor = $2000 \times 2.212 \times 10^{-3}$ = 4.42 hours

Energy = $(15918+3725/40.6+1.308 \times 10^9/138690) \times 2.212 \times 10^{-3}$ = 56.3 Gallons

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(a) For an evaporator/crystallizer processing 15963 ft^3 of waste annually.

(b) 1984 costs given in reference 3 are divided by $(1.13)^2$ given in that reference to get 1980 costs.

(c) Source : Reference 3, Table K.122. Capital costs include equipment, piping and instrumentation, electrical, and building (40'x25'x25').

(d) Source : Reference 3, Table K.123. Labor costs have been modified to 1980 costs by dividing with $(1.1)^4$ as suggested in that reference.

(e) $2.212 \times 10^{-3} = 35.315\ ft^3/m^3\ /\ 15963\ ft^3$.

The unit rates for a pathological incinerator processing 7360 ft^3 of trash per year are also based on reference 3 data, however, labor hour requirements, which are used in occupational exposure calculations, have been reduced to 40% of the labor hours due to the comparatively low activity levels of waste that will be handled by pathological incinerators. These rates are summarized in Table 5-6.

In this report it is assumed that calciner/incinerators can process trash in addition to other wastes such as LWR evaporator bottoms and spent ion-exchange resins. Two types of calciners are considered in this report. One is located at a centralized processing facility (which may be located at the disposal site) with a large annual processing volume - assumed to be 46,200 ft^3, and the second one is located at an individual waste generating facility with a smaller annual processing volume - assumed to be 23,100 ft^3.(3) The capital costs, annual maintenance and consumables for these two units have been assumed to be the same, however, the labor costs and utilities have been modified for the reduced volume of waste processed per year. The unit rates for these two incinerators have also been obtained from reference 3 and are summarized in Tables 5-7 and 5-8.

Solidification costs are strongly dependent on the solidification agent used. For example, cement is the cheapest material, however, it requires the most elaborate equipment for solidification. The properties of the solidification scenarios have been simulated by 50% urea-formaldehyde and 50% cement in solidification scenario A, 50% cement and 50% synthetic polymer (e.g., vinyl ester styrene - VES) in solidification scenario B, and 100% synthetic polymer in solidification scenario C. The solidification costs utilized in this report have been obtained from reference 6 assuming an annual processing volume of 12,000 ft^3 for the purpose of estimating the capital cost portion of the costs. These costs and other unit rates are presented in Table 5-9.

TABLE 5-6 . Pathological Incinerator Unit Rates[a]

Item	(1980 $)[b]
Total Capital Cost[c]	$6,544,068
First Year Cost	218,136
Annual Operating Costs[d]	
Labor - 4160 person-hours	74,880
Maintenance and Consumables	132,000
Utilities 24,000 kW-hr	2,184
240×10^6 BTU	1,990
Total :	$429,190

Unit Rates[e] per m^3 of input:

Costs = $429190 \times 4.8\times10^{-3}$ = $ 2060

Labor = $4160 \times 4.8\times10^{-3}$ = 20 hours[f]

Energy = $(21814+24000/40.6+240\times10^{6}/138690)$
$\times4.8\times10^{-3}$ = 116 Gallons

(a) For a controlled air incinerator processing 7360 ft^3 of waste annually.

(b) 1984 costs given in reference 3 are divided by $(1.13)^2$ given in that reference to get 1980 costs.

(c) Source : Reference 3, Table K.64. Capital costs include equipment, piping and instrumentation, electrical, and building (30'x40'x40').

(d) Source : Reference 3, Table K.65. Labor costs have been modified to 1980 costs by dividing with $(1.1)^4$ as suggested in that reference.

(e) $4.8\times10^{-3} = 35.315\ ft^3/m^3\ /\ 7360\ ft^3$.

(f) Only 40% of the labor hours are considered in occupational exposure calculations (8 hours) due to very low activity waste being processed.

TABLE 5-7 . Large Processing Volume Calciner/Incinerator Unit Rates[a]

Item	(1980 \$)[b]
Total Capital Cost[c]	\$21,193,589
First Year Cost	706,453
Annual Operating Costs[d]	
Labor - 7000 person-hours	126,000
Maintenance and Consumables	440,000
Utilities 945,000 kW-hr	85,995
	Total : \$1,358,448

Unit Rates[e] per m^3 of input:

Costs = $1358448 \times 7.65\times10^{-4}$ = \$ 1039

Labor = $7000 \times 7.65\times10^{-4}$ = 5.35 hours

Energy = $(70645+945000/40.6) \times 7.65\times10^{-4}$ = 72 Gallons

---

(a) For a calciner/incinerator processing 46200 ft^3 of waste annually.

(b) 1984 costs given in reference 3 are divided by $(1.13)^2$ given in that reference to get 1980 costs.

(c) Source : Reference 3, Table K.91. Capital costs include equipment, piping and instrumentation, electrical, and building (52'x50'x60').

(d) Source : Reference 3, Table K.92. Labor costs have been modified to 1980 costs by dividing with $(1.1)^4$ as suggested in that reference.

(e) $7.65\times10^{-4} = 35.315\ ft^3/m^3\ /\ 46200\ ft^3$.

TABLE 5-8 . Small Processing Volume Calciner/Incinerator Unit Rates[a]

Item	(1980 $)[b]
Total Capital Cost[c]	$21,193,589
First Year Cost	706,453
Annual Operating Costs[d]	
Labor - 4000 person-hours	72,000
Maintenance and Consumables	440,000
Utilities 540,000 kW-hr	49,140
Total :	$1,267,593

Unit Rates[e] per m^3 of input:

Costs = $1267593 \text{ x } 1.529\text{x}10^{-3}$ = $ 1938

Labor = $4000 \text{ x } 1.529\text{x}10^{-3}$ = 6.12 hours

Energy = $(70645+540000/40.6) \text{ x } 1.529\text{x}10^{-3}$ = 129 Gallons

---

(a) For a calciner/incinerator processing 23,100 ft^3 of waste annually.

(b) 1984 costs given in reference 3 are divided by $(1.13)^2$ given in that reference to get 1980 costs.

(c) Source : Reference 3, Table K.91. Capital costs include equipment, piping and instrumentation, electrical, and building (52'x50'x60').

(d) Source : Reference 3, Table K.92. Labor and utilities have been multiplied by 4/7 because of the reduced volume, and labor costs have been modified to 1980 costs by dividing with $(1.1)^4$ as suggested in that reference.

(e) $1.529\text{x}10^{-3} = 35.315 \text{ ft}^3/\text{m}^3 / 23100 \text{ ft}^3$.

TABLE 5-9 . Solidification Unit Rates

Item	(1980 $)
Scenario A : Total Capital[a]	$3,520,000
First Year Cost	117,333
Operating Costs[a]	$26.50/ft^3
Unit Rates[b]	
Costs : 35.315x(26.5+117,333/12000) = $ 1282/m^3	
Labor : 24 person-hours/m^3	
Energy Use : 40 gallons/m^3	
Scenario B : Total Capital[a]	$3,520,000
First Year Cost	117,333
Operating Costs[a]	$43.25/ft^3
Unit Rates[b]	
Costs : 35.315x(43.25+117,333/12000) = $ 1873/m^3	
Labor : 24 person-hours/m^3	
Energy Use : 40 gallons/m^3	
Scenario C : Total Capital[a]	$3,320,000
First Year Cost	110,666
Operating Costs[a]	$60.00/ft^3
Unit Rates[b]	
Costs : 35.315x(60.0+117,333/12000) = $ 2445/m^3	
Labor : 24 person-hours/m^3	
Energy Use : 40 gallons/m^3	

(a) Source : Reference 6. Capital costs are from Table K.10, operating costs are from Table K.7. Scenario A cost is taken equal to the cement case, scenario B is taken equal to the average of cement and VES cases, and scenario C is the VES case.

(b) Labor requirements for all scenarios are assumed to be the same and taken equal to 24 person-hours/m^3 (5 man hours per drum) as given in Reference 3, Table K.16.

In estimating these unit rates, it has been assumed that the primary difference in the unit costs results from the solidification material costs. For solidification scenario A, it has been further assumed that the lower costs for the simpler equipment required for the urea-formaldehyde solidification is balanced by higher material costs and that it may be represented by the cement case. The manpower requirements used for estimating the occupational exposures have been assumed to be the same for all scenarios.

The energy use has been estimated to be approximately the same for all scenarios, since the difference in unit costs for solidification scenarios are attributable to material costs. The energy use for all scenarios has been assumed to be 3 percent of the solidification scenario A unit cost.

REFERENCES FOR CHAPTER 5.0

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3. Trigilio, G., Teknekron, Inc., "Volume Reduction Techniques in Low-Level Radioactive Waste Management," USNRC Report NUREG/CR-2206,

4. Johnson, T., Low-Level Waste Branch, U.S. Nuclear Regulatory Commission, Personal Communication, 1981.

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6.0 IMPACTS ANALYSES CODES

This chapter presents and discusses the computer programs written to calculate impact measures associated with the management of low-level radioactive waste (LLW). Three phases of waste management which may result in impacts are considered: waste processing, transportation, and disposal. The impact measures are calculated utilizing: (1) information on waste characteristics(1) (2) data and assumptions on disposal technologies and disposal site environment presented in Appendix C and reference 2, and (3) the impact calculational methodologies presented in Chapters 3.0 through 5.0 of this report.

Section 6.1 is an introduction to the chapter and provides a discussion of the applicability of the analyses to generic versus specific disposal technologies, and presents the background rationale for separating the analyses into the components presented in the subsequent sections. Following this section, discussions of five codes utilized to perform impact calculations are presented in Section 6.2. Included in the discussions are the assumptions utilized, the general structure of the computer code employed, and an example of the results of the codes. General parameters common to all the codes are presented in Section 6.3, and the listing of the computer programs and the data bases employed are presented in Appendix D.

6.1 Introduction

This section presents the basic assumptions utilized in this chapter. The discussion presented includes the purpose of the analyses, the data base and the general approach adopted to compartmentalize the analyses into five separate codes, and an overview of the five codes including the approaches utilized in selection of the cases considered.

6.1.1 Purpose

The purpose of the alternatives analyses is the need for a systematic examination of the impacts resulting from the management and disposal of LLW taking into consideration the extremely wide range of variability in the available alternatives. This systematic examination permits identification of specific values of parameters that can be controlled and/or specified through technological or administrative action so as to assure the disposal of LLW in accordance with the goals of LLW management and disposal.

The impacts considered in this systematic examination include longer term safety considerations, short-term safety during operations, long-term socioeconomic committment, and long- and short-term radiological exposures -- occupational as well as to the members of the public. In view of past disposal history,(3) long-term performance of the disposal system is stressed in the impacts analyses performed. The long-term performance may be quantified through potential radiological impacts and long-term socioeconomic impacts.

The secondary purpose of the alternatives analyses is to generically quantify and assess the impact measures for selected alternatives. These generic results may be utilized as a first estimate of the actual impacts associated with a proposed disposal alternative, however, site specific information obtained during the licensing phase would permit a more accurate assessment of these impacts.

6.1.2 Summary of Data Bases

The alternatives to be considered result from the variation of parameter values associated with three major aspects of LLW management and disposal. These aspects are disposal technology properties, waste form and packaging properties, and dose limitation criteria applicable for specific human organs. The first two of these aspects of LLW management and disposal have been summarized in Chapter 3.0 in the form of indices.

The disposal technology properties have been quantified through thirteen indices called the disposal technology indices (see Section 3.2). These indices are read into all the computer programs through an array called IRDC. The effects of all the indices and associated information, except for the region index IR, have been incorporated into the internal structure of the computer codes. The data associated with the region index is read into the program from an information file called TAPE1. The waste form and packaging properties have similarly been quantified through waste form behavior indices (see Section 3.3). Waste form behavior indices have been specified for 36 different waste streams (resulting from different waste generating sources), and for four different waste spectra resulting from alternative waste processing methodologies which may be adopted by the waste generators or at a central processing facility. These waste spectra are summarized in Table 6-1.

There are two comparatively distinct information bases associated with the waste streams: one information base details the basic radiological characteristics of the waste streams; the other details the behavior of the waste form under different waste spectra. The first information base is stored in an array called BAS, and is also read into the computer programs from TAPE1. The second information base is stored in an array called ISPC, and is read into the computer programs through an information file called TAPE2.

The third aspect of the LLW management and disposal to be considered in the alternatives analyses -- the dose limitation criteria -- has been discussed in reference 2. Finally, the last set of basic information utilized in all the computer programs is on the radionuclides and the pathway dose conversion factors. This data is stored in several arrays (see Section 6.3), and is also read into the computer programs from TAPE1.

TABLE 6-1 . Summary Description of Waste Spectra

Waste Spectrum 1

This spectrum assumes a continuation of existing waste management practices. Some of the LWR wastes are solidified; however, no processing is done on organics, combustible wastes, or streams containing chelating agents. LWR resins and filter sludges are assumed to be shipped to disposal sites in a dewatered form. LWR concentrated liquids are assumed to be concentrated in accordance with current practices, and are solidified with various media designated as solidification scenario A.* No special effort is made to compact trash. Institutional waste streams are shipped to disposal sites after they are packaged in currently utilized absorbent materials. Resins from LWR decontamination operations are solidified in a medium with highly improved characteristics (solidification scenario C).

Waste Spectrum 2

This spectrum assumes that LWR process wastes are solidified using improved solidification techniques (solidification scenario B). LWR concentrated liquids are additionally reduced in volume, to 50 weight percent solids, using an evaporator/crystallizer. All other high activity waste streams are stabilized using improved waste packaging techniques. In the case of cartridge filters, the solidification agent fills the voids in the packaged waste but does not increase the volume. Liquid scintillation vials are crushed at large facilities and packed in absorbent material. All compactible trash streams are compacted; most at the source of generation and some at a regional processing center. Liquids from medical isotope production facilities are solidified using solidification scenario C procedures.

Waste Spectrum 3

In this spectrum, LWR process wastes are solidified assuming that further improved solidification agents are used (solidification scenario C). LWR concentrated liquids are first evaporated to 50 weight percent solids. All possible incineration of combustible material (except LWR process wastes) is performed; some incineration is done at the source of generation and some at a regional processing center. All incineration ash is solidified using solidification scenario C procedures. All other high activity wastes are again stabilized using improved packaging techniques.

Waste Spectrum 4

This spectrum assumes extreme volume reduction. All waste amenable to evaporation or incineration with fluidized bed technology are calcined and solidified using solidification scenario C procedures; LWR process wastes, except cartridge filters, are calcined in addition to the streams incinerated in Spectrum 3. All non-compactible wastes are reduced in volume at a regional processing facility using a large hydraulic press. This spectrum represents the maximum volume reduction that can be currently practically achieved.

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* Solidification scenario A : 50% urea-formaldehyde and 50% cement.
Solidification scenario B : 50% cement and 50% synthetic polymer.
Solidification scenario C : 100% synthetic polymer.

A very large number of alternatives result from the variability of values associated with these three aspects of LLW management and disposal. For example, for each region (IR), post operational period (IPO), and active institutional control period (IIC), there are 5184 possible permutations of the remaining disposal technology indices. Therefore, the analyses of alternatives must utilize computer programs to rapidly calculate and assess the impacts. Furthermore, several computer programs are needed to examine and assess an isolated portion of the decision base that is produced by the analyses. Only in this systematic manner may one fully utilize the flexibility and detail provided by the information base.

6.1.3 General Approach

As stated previously, long-term performance of the disposal system is stressed in this report. In the analyses of the radiological impacts, there are three major potential modes of exposure (see Chapter 2.0) two of which relate to longer term safety consideration: humans inadvertantly contacting the waste after disposal (which involves the concentration of radionuclides in the waste), and the waste entering one of several natural pathways leading back to biota which involves the total activity disposed at the site.

The fact that impacts from scenarios involving direct human intrusion into disposed waste are governed by the radionuclide concentrations in the particular waste streams assumed to be contacted makes the intruder scenarios very useful for waste classification purposes. Assuming that a limit is placed on the exposures allowed to a potential human intruder, then the maximum allowable concentrations of radionuclide in waste streams to meet this exposure limit may be calculated. Once concentration limits are determined, waste generators can relatively easily determine what class their waste belongs to by comparing the radionuclide concentrations in their wastes with the limiting concentrations determined through the intruder scenarios.

By contrast, it is much more difficult to classify wastes through use of total activity scenarios such as groundwater migration since impacts from groundwater migration are much more dependent on site specific conditions than the intruder scenarios. In addition, since the potential impacts are a function of the total activity of waste disposed, it is difficult to set concentration limitations for individual radionuclides to meet a specific dose limitation criteria. It would be difficult, based upon groundwater migration considerations, to set concentration limits that can be used by a waste generator to determine the classification of his waste.

It is important to emphasize, however, that this does not mean that groundwater migration from a disposal facility is not an important consideration in LLW disposal. It does suggest that rather than establishing concentration limitations to be met by a waste generator to meet a particular groundwater exposure limitation criteria, it would probably be more useful to set an inventory limitation for a particular disposal facility (based upon site-specific information) for particular radionuclides of concern.

6.1.4 Overview of Computer Codes

In view of the above discussion, therefore, the first step in the alternatives analyses involves examination of the acceptable disposal requirements of the waste streams. This is performed through a code called INTRUDE (see Section 6.2.1) which determines the radiological impacts resulting from potential inadvertant human intrusion into a selected disposal facility containing waste processed through one of the above waste spectra as a function of time after disposal.

The second step in the alternatives analyses involves determination of long-term radiological and non-radiological impacts including those which may result from potential groundwater migration. These analyses are performed through two codes called GRWATER and OPTIONS.

Attention is principally focused upon long-term radiological impacts of potential inadvertant intrusion into disposed wastes and potential groundwater migration of radionuclides, as well as potential long-term costs to a site owner for surveillance and control of a closed disposal facility. A number of alternatives for waste form and packaging, and disposal facility design and practices are examined for means to mitigate or reduce these potential long-term radiological and cost impacts. As a byproduct of implementing these alternatives, however, there are short-term costs such as waste processing, transportation, and disposal costs as well as short-term radiological impacts such as occupational exposures during waste handling and population exposures due to waste processing and transportation.

The code GRWATER calculates the individual exposures resulting from use of contaminated water drawn from various human access locations such as a well that may become contaminated as a result of potential groundwater migration of radionuclides. These radiological impacts are examined for several sets of disposal technology indices and a selected waste spectrum. Exposures are calculated as a function of time and may be presented as (1) total exposures from the contribution of all waste streams, (2) total exposures from a particular waste stream or group of waste streams, and (3) exposures from each of the radionuclides considered.

The OPTIONS code calculates the waste volume-averaged inadvertant intruder impacts, impacts resulting from exposed waste scenarios, as well as impacts resulting from operational accidents and impacts associated with short term considerations such as waste processing and transportation impacts, disposal costs, energy use, land use, etc.

In addition to these three codes which consider projected low-level waste characteristics, two codes have been programmed to calculate limiting concentrations in waste streams and total inventories in disposal facilities for specific cases. One of these codes is called

INVERSI and calculates the limiting concentrations in waste to meet a specific dose criterion for a specific disposal facility design; it is used for waste classification purposes. The other code is called INVERSW and calculates disposal facility radionuclide concentrations and inventories to meet specific allowable dose criteria for groundwater migration for a specific disposal facility design and regionally representative environmental characteristics; it may also be used for waste classification purposes.

Computer listings of the codes utilized to perform the analyses are presented in Appendix D. The codes have been designed to optimize execution (running) time rather than memory. They have been executed in a CDC-6600 computer in a time sharing mode. They use just two lines of input: an IRDC(12) array which contains the disposal technology indices presented in above, and a NOTE(6) array which is a 60 character descriptive title that can be arbitrarily set. The rest of the data is input to the codes through two tapes: TAPE1, which contains most of the generic data (see Section 6.3), and TAPE2 which contains waste spectrum specific information. A listing of these tapes is also presented in Appendix D.

Alteration of the codes for other systems should be relatively easy since they use only standard FORTRAN functions that are commonly used. Output formats and statements, however, should be closely checked, since they vary significantly from one computer system to the next.

6.1.5 Discussion

The alternatives analyses enable safety decisions (in addition to those decisions resulting from the inadvertant intruder and groundwater impacts analyses) to be made on performance objectives and technical requirements for acceptable disposal of LLW. These performance objectives and technical requirements may then be summarized in a waste classification system that is addressed to waste generators and whose primary objective is flexibility and practicality.

The most important limitation for the applicability of the analyses and its results is the generic nature of the analysis, i.e. utilization of generic waste spectra, generic disposal facility environments, generic radiological impact analyses methodologies, etc. Similar, and possibly, much more detailed, analyses are likely to be necessary to establish the potential impacts resulting from the disposal of LLW at a particular disposal facility.

6.2 Description of the Codes

6.2.1 INTRUDE Code

In determining performance objectives and technical requirements for LLW disposal, an important consideration is the potential for human intrusion into the disposed waste. Such intrusion may act to increase the potential for groundwater migration by increasing the infiltration of precipitation into the waste and it may also bring wastes to the surface where they may potentially be dispersed by wind or water. These actions may result in radiation exposures to the surrounding population. However, the largest radiation exposures by far would be to the intruders themselves.

There are three basic scenarios for intruder exposure: potential construction of a house on the disposal site, persons potentially living in a house located in contaminated soil and consuming vegetables grown in an onsite garden, and the use of contaminated water from an on-site well. This section and accompanying code considers the first two of these scenarios: intruder-construction and intruder-agriculture scenarios. The third scenario, intruder-well scenario, is considered in the next section on groundwater impacts analyses. The potential exposures to the surrounding population as a result of the actions of the intruder, the exposed waste scenarios, are considered in the following section on alternatives analyses.

There are three principal means of controlling potential exposures to an intruder: use of institutional controls, use of natural and/or engineered barriers which would make it more difficult for an intruder to contact the waste, and use of less dispersible waste forms. None of these controls can be assumed to be functional forever. However, an important decision to be made at the time of disposal for a given waste stream is whether it requires special considerations with regards to institutional controls, waste form, and natural and/or engineered barriers. INTRUDE performs a screening analyses to determine which waste stream (or streams when mixed and disposed together) requires special consideration.

The code calculates seven human organ doses resulting from the "standard" or modified intruder-construction scenario and the "standard" or modified intruder-agriculture scenario (see Section 3.4) as a function of time. Also calculated are the ICRP weighted exposures summed over all the organ doses. This yields an initial definition of what is acceptable for near surface disposal under the reference disposal conditions. The disposal technology indices selected for the screening analysis are presented below:

IR = 2
ID = 1
IC = 1
IX = 1
IE = 1

IS = 0
IL = 0
IG = 0
IH = 0
IQ = 1

In addition, the closure period (i.e., IPO) is assumed to be 2 years, and the active institutional control period (i.e., IIC) is varied from 50 years to 2000 years.

In the analyses, all four waste spectra (see Table 6-1) are considered one by one. A number of different analyses may be performed for different groups of waste streams for a given waste spectrum. Four such potential groupings are the following:

- Each waste stream separately (36 separate analyses);
- Waste streams in four macroscopic groups;
- Waste streams in five major waste generation sources;
- All the waste streams together.

During the screening analyses performed by INTRUDE, dose limitation criteria are not needed as input since the purpose of the analysis is to determine the acceptable disposal requirements of the wastes and not to classify them. It should be noted that the intruder-pathway analyses may also be changed easily to perform sensitivity analyses to determine the effect on results of different assumptions for indices such as the waste form behavior indices.

An example output of the code is presented in Table 6-2 for the above set of disposal technology indices. Waste spectrum 2 is assumed, and impacts are presented for the first group of 7 waste streams (LWR process waste streams) shown on Table 3-4. It should be pointed out, however, that the code can be executed for an arbitrary set of disposal technology indices.

6.2.2 GRWATER Code

This section discusses GRWATER, which is a code written to perform an assessment of the impacts from groundwater migration of radionuclides with emphasis on waste form and packaging performance parameters, and site selection and design parameters. After classification of the waste streams into categories in accordance with the test procedure outlined in Section 3.4 and the dose limitation criteria specified in the code as acceptable, the code computes seven human organ doses as a function of time after closure of the disposal facility for several biota access locations.

There are three basic scenarios for direct or indirect exposure of humans to radioactivity from potential groundwater migration: an individual-well scenario which envisions drilling of a well either

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TABLE 6-2. Example INTRUDE Output

```
IR = 2  ID = 1  IC = 1  IX = 1
IE = 1  IS = 0  IL = 0  IG = 0
IH = 0  ICL=12  IPD= 2 YEARS  100


GROUP NO = 1

YR =  50.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  1.409E+04 1.412E+04 1.412E+04 1.409E+04 1.410E+04 1.410E+04 1.409E+04 2.044E+04
 INT-AGRI  1.670E+04 1.675E+04 1.670E+04 1.671E+04 1.669E+04 1.669E+04 1.669E+04 2.422E+04

YR = 100.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  4.347E+03 4.371E+03 4.367E+03 4.345E+03 4.355E+03 4.354E+03 4.344E+03 6.308E+03
 INT-AGRI  5.150E+03 5.174E+03 5.155E+03 5.166E+03 5.149E+03 5.148E+03 5.149E+03 7.471E+03

YR = 150.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  1.373E+03 1.395E+03 1.391E+03 1.372E+03 1.381E+03 1.379E+03 1.371E+03 1.996E+03
 INT-AGRI  1.626E+03 1.640E+03 1.632E+03 1.645E+03 1.628E+03 1.627E+03 1.624E+03 2.361E+03

YR = 200.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  4.362E+02 4.562E+02 4.526E+02 4.357E+02 4.438E+02 4.418E+02 4.348E+02 6.369E+02
 INT-AGRI  5.160E+02 5.264E+02 5.223E+02 5.360E+02 5.186E+02 5.177E+02 5.151E+02 7.507E+02

YR = 300.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  4.790E+01 6.511E+01 6.203E+01 4.769E+01 5.447E+01 5.271E+01 4.675E+01 7.327E+01
 INT-AGRI  5.595E+01 6.372E+01 6.154E+01 7.643E+01 5.856E+01 5.777E+01 5.596E+01 8.336E+01

YR = 400.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  9.193E+00 2.445E+01 2.164E+01 9.121E+00 1.494E+01 1.361E+01 8.187E+00 1.672E+01
 INT-AGRI  1.018E+01 1.677E+01 1.512E+01 3.076E+01 1.250E+01 1.189E+01 9.876E+00 1.679E+01

YR = 500.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  5.214E+00 1.897E+01 1.634E+01 5.252E+00 1.027E+01 9.460E+00 4.317E+00 1.064E+01
 INT-AGRI  5.549E+00 1.137E+01 9.953E+00 2.618E+01 7.598E+00 7.192E+00 5.290E+00 9.932E+00

YR =1000.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  4.287E+00 1.361E+01 1.137E+01 4.657E+00 7.189E+00 8.384E+00 3.722E+00 8.403E+00
 INT-AGRI  4.705E+00 8.605E+00 7.501E+00 2.547E+01 5.897E+00 6.295E+00 4.579E+00 8.536E+00

YR =2000.     BODY      BONE       LIVER     THYROID     KIDNEY     LUNG     G-I TRACT    ICRP
 INT-CONS  3.859E+00 1.010E+01 8.141E+00 4.459E+00 5.261E+00 7.874E+00 3.522E+00 7.165E+00
 INT-AGRI  4.373E+00 7.020E+00 6.056E+00 2.523E+01 4.966E+00 5.931E+00 4.337E+00 7.605E+00
```

adjacent to a disposal cell or at the site boundary, a population-well scenario which envisions pumping water from a well to satisfy the needs of a small community located between the disposal facility and an open water location receiving groundwater passing underneath the site, and a population-surface water scenario which assumes that population exposures result from consumption and utilization of open water that has received discharge from contaminated groundwater passing underneath the site.

All three of these scenarios are relatively unlikely to occur, especially considering the conservative assumptions that have been made for the migration analysis (see Section 3.5 and Appendix A). In addition, for example, an intruder in need of water is likely to drill a well where the groundwater is closer to the surface and where water yields are more substantial. The potentially low water yields in these wells are due to the comparatively low saturated zone hydraulic velocity resulting from location of the disposal site at a topographic high, which usually indicates that the location is near or at a groundwater divide. Similar arguments are applicable for the population-well scenario. Even a small community's water needs are substantial, especially considering the fact that this community is likely to be a farming community.

The results of the groundwater impacts analysis may be used to determine if a limitation on the total activity of the waste disposed at the site need be considered. In addition it may be used to recommend minimum groundwater release standards for some of the wastes.

An idealized map of the disposal facility showing the areal relationships of the disposal site and the groundwater access locations was shown in Figure 3.3. As indicated in the figure, the transverse (i.e., perpendicular to the groundwater flow direction) dispersion of the contaminants before and after they reach the saturated zone is measured through the geometric reduction factor (r_g). However, the dispersion of the contaminants in the direction of groundwater flow is dependent on the longitudinal (parallel to the groundater flow direction) extent of the disposal facility. Currently, there does not exist a closed-form analytical solution of the areally distributed source groundwater migration problem; only approximations of the equations or numerical integrations of the point-source equations are available.

The longitudinal extent of the disposal site is taken into account in the analysis by the application of the point-source equations given in Chapter 3.0 to each of 10 sectors. In this manner, the transverse distribution is taken into account through the factor (r_g), and the longitudinal distribution of the source is numerially integrated.

In this calculation, water starting from each of the sectors has different travel times to the three access locations. This travel time is calculated in the computer code through the use of an incremental travel time and Peclet number between the sectors (the DTTM and DTPC arrays), through dividing the source term into 10 equal parts (this is conservative since the higher specific activity waste is likely to have higher surface radiation levels and is likely to be placed at the center of the disposal site due to occupational health considerations), and placing this source at the center of each sector.

This division of the source term into 10 sectors is significantly more realistic and conservative than a single point source at the center of the disposal facility. This is due to the additional decay afforded to the comparatively fast travelling radionuclides such as tritium and carbon-14. The rest of the groundwater migration assumptions have been presented in Section 3.5. The code has several options built into it:

(1) it can consider different dose limitation criteria in the initial classification of the wastes into regular, layered, or hot waste facility wastes.

(2) it can exclude a waste stream or group of waste streams from the analysis through the use of the NDX(36) array.

(3) it can package a waste stream or group of waste streams in high integrity containers thereby postponing the initiation of the groundwater migration scenario for those streams for a specified period of time, and/or stabilizing the waste streams,

(4) it has the option to perform a time dependent source term calculation, and increase the released source term after an intruder and/or time causes percolation values to increase,

(5) it can provide the total exposures from the contribution of all the radionuclides in all the streams, total exposures from all the radionuclides from a particular waste stream or group of streams, or exposures from each of the radionuclides considered in all or some of the waste streams.

A portion of an example output of GRWATER is presented in Table 6-3 for the case of waste spectrum 2, and the following disposal facility indices:

IR = 2 ID = 1 IC = 2 IX = 2
IE = 1 IS = 1 IL = 1 IG = 0
IH = 1 IQ = 1 ICL = 2
IPO = 2 years IIC = 100 years

6.2.3 OPTIONS Code

The previous two codes, INTRUDE and GRWATER, concentrate on the long-term radiological impacts resulting from the disposal of LLW. However, in a generic analysis to determine performance objectives and technical requirements for management and disposal of LLW, other impact measures must be included in the information base for decision making. Moreover, a comparative analysis of the intruder impacts averaged over all the streams within their respective disposal status is useful in the decision making process. This section presents a code for calculating this decision base.

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TABLE 6-3. Example GRWATER Output

```
SPECTRUM  2
IR = 2  ID = 1  IC = 2  IX = 2
IE = 1  IS = 1  IL = 1  IG = 0
IH = 1  ICL=12  IPO= 2 YEARS  100
VREG = 6.78E+05 VLAY = 0.       VHOT = 0.       VNOT - 1.94E+04

YR =   40.     BODY        BONE        LIVER     THYROID   KIDNEY      LUNG     G-I TRACT     ICRP
 BOU-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   50.     BODY        BONE        LIVER     THYROID   KIDNEY      LUNG     G-I TRACT     ICRP
 BOU-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   60.     BODY        BONE        LIVER     THYROID   KIDNEY      LUNG     G-I TRACT     ICRP
 BOU-WELL  3.536E-03 2.125E-10 3.536E-03 3.536E-03 3.536E-03 3.536E-03 3.536E-03 4.703E-03
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   70.     BODY        BONE        LIVER     THYROID   KIDNEY      LUNG     G-I TRACT     ICRP
 BOU-WELL  1.111E+00 6.672E-08 1.111E+00 1.111E+00 1.111E+00 1.111E+00 1.111E+00 1.477E+00
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   80.     BODY        BONE        LIVER     THYROID   KIDNEY      LUNG     G-I TRACT     ICRP
 BOU-WELL  6.543E-01 3.931E-08 6.543E-01 6.543E-01 6.543E-01 6.543E-01 6.543E-01 8.702E-01
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =   90.     BODY        BONE        LIVER     THYROID   KIDNEY      LUNG     G-I TRACT     ICRP
 BOU-WELL  3.726E-01 2.238E-08 3.726E-01 3.726E-01 3.726E-01 3.726E-01 3.726E-01 4.956E-01
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.

YR =  100.     BODY        BONE        LIVER     THYROID   KIDNEY      LUNG     G-I TRACT     ICRP
 BOU-WELL  2.122E-01 1.275E-08 2.122E-01 2.122E-01 2.122E-01 2.122E-01 2.122E-01 2.822E-01
 POP-WELL  0.          0.          0.          0.          0.          0.          0.          0.
 POP-SURF  0.          0.          0.          0.          0.          0.          0.          0.
```

The decision base includes five major components: (1) the volumes of waste requiring different disposal practices -- i.e., the volumes in each disposal status which varies depending on the disposal technology indices and waste form behavior parameters determined by the waste spectrum assumed, (2) disposed waste volume-averaged inadvertant intruder impacts; (3) radiological impacts resulting from potential exposed waste scenarios; (4) exposures which may result from abnormal operating conditions (accident scenarios); and finally (5) the impact measures associated with the different phases of LLW management and disposal (i.e., waste processing, transportation, disposal) consisting of costs, occupational exposures, population exposures, energy use, and land use. The OPTIONS code calculates these five items. All radiological impacts calculated (except occupational exposures which are total body exposures) calculated include seven human organs.

The volumes of waste in each disposal status, however, have further been divided within each major category -- i.e., regular, layered, and hot waste facility wastes -- into four subcategories: stable with no chemical agents, stable with chemical agents, unstable with no chemical agents and unstable with chemical agents.

The code has most of the options considered in the GRWATER code. For example, it can consider different dose limitation criteria in the initial classification of the wastes, it can exclude streams from the analysis, etc. A portion of an example output of OPTIONS is presented in Tables 6-4 and 6-5 for the GRWATER code example case.

6.2.4 INVERSI and INVERSW Codes

The inverse codes calculate the maximum allowable concentrations that may be disposed within the radiological guidelines considered (maximum exposure limits) and various disposal technology properties. There are two inverse codes: intruder (INVERSI), and groundwater (INVERSW). In each case, the maximum allowable concentrations for a given set of

TABLE 6-4 . Example OPTIONS Output - I

```
OPTIONS PROGRAM    IAM REPORT    SPECTRUM 2

DISPOSAL TECHNOLOGY INDICES
IR = 2  ID = 1  IC = 2  IX = 2
IE = 1  IS = 1  IL = 1  IG = 0
IH = 1  ICL=12  IPO= 2  IIC= 100

REGULAR WASTE :                      6.784E+05 M**3
     CH-STAB    I-LQSCNVL 3.182E+04
                I+ABSLIQD 4.628E+03
                N-ISOPROD 2.871E+03
                N-TRITIUM 9.616E+02
                TOTAL VOLUME  :      4.028E+04 M**3
     CH-UNSTAB  I+LQSCNVL 4.072E+04
                I-BIOWAST 8.332E+03
                I+BIOWAST 8.332E+03
                N-LOWASTE 1.665E+04
                TOTAL VOLUME  :      7.404E+04 M**3
     NCH-STAB   P-IXRESIN 1.578E+04
                P-CONCLIQ 2.040E+04
                P-FSLUDGE 1.950E+03
                P-FCARTRG 6.014E+03
                B-IXRESIN 3.475E+04
                B-CONCLIQ 3.774E+04
                B-FSLUDGE 7.703E+04
                P-NCTRASH 6.017E+04
                B-NCTRASH 2.734E+04
                F-PROCESS 2.159E+04
                U-PROCESS 7.765E+03
                I-ABSLIQD 2.546E+03
                N-SSWASTE 1.751E+04
                L-NFRCOMP 7.975E+02
                N-HIGHACT 7.204E+02
                N-TARGETS 3.702E+02
                TOTAL VOLUME  :      3.325E+05 M**3
     NCH-UNSTAB P-COTRASH 5.862E+04
                B-COTRASH 2.881E+04
                F-COTRASH 4.344E+04
                F-NCTRASH 1.152E+04
                I-COTRASH 1.943E+04
                I+COTRASH 9.717E+03
                N-SSTRASH 3.308E+04
                N+SSTRASH 1.654E+04
                N-LOTRASH 6.994E+03
                N+LOTRASH 3.497E+03
                TOTAL VOLUME  :      2.317E+05 M**3

HOT WASTE     :                      1.938E+04 M**3
                L-DECONRS 1.933E+04
                N-SOURCES 5.152E+01
```

TABLE 6-5 . Example OPTIONS Output - II

```
INTRUDER IMPACTS
            BODY      BONE      LIVER    THYROID    KIDNEY     LUNG    G-I TRACT   ICRP
REC-CONS  3.333E+01 3.342E+01 3.336E+01 3.332E+01 3.333E+01 3.335E+01 3.332E+01 4.834E+01
REC-AGRI  2.081E+01 2.509E+01 1.952E+01 1.954E+01 1.951E+01 1.951E+01 1.966E+01 3.027E+01
REC-CONS  1.646E+00 1.705E+00 1.688E+00 1.645E+00 1.666E+00 2.094E+00 1.642E+00 2.451E+00
REC-AGRI  2.066E+00 2.705E+00 2.089E+00 2.624E+00 2.070E+00 2.236E+00 2.064E+00 3.111E+00
REC-CONS  1.447E+00 2.799E+00 2.364E+00 1.378E+00 1.742E+00 2.748E+00 1.375E+00 2.483E+00
REC-AGRI  1.764E+00 2.759E+00 2.137E+00 2.292E+00 1.896E+00 2.275E+00 1.740E+00 2.783E+00


EXPOSE/ACC IMPACTS
REC-AIR   1.624E-02 7.231E-02 9.556E-03 5.893E-04 4.910E-03 6.941E-03 1.839E-03 2.674E-02
ERO-AIR   6.099E+00 1.196E+02 7.924E+01 6.426E+01 2.744E+01 1.085E+02 3.541E-01 4.181E+01
REC-WAT   1.972E-03 5.986E-03 1.441E-03 1.043E-04 5.570E-04 2.357E-04 2.465E-04 2.857E-03
ERO-WAT   8.847E-02 7.014E-01 1.411E-01 9.899E-01 1.073E-01 5.389E-02 1.806E-01 2.345E-01
ACC-SNGC  7.573E-02 2.279E-01 1.249E-01 4.581E-02 8.075E-02 8.561E-01 4.848E-02 2.224E-01
ACC-FIRE  1.272E+01 4.059E+01 2.108E+01 6.872E+00 1.357E+01 6.130E+01 5.375E+00 2.755E+01
ACC-AVG   5.935E+00 1.893E+01 9.836E+00 3.210E+00 6.331E+00 2.887E+01 2.517E+00 1.289E+01


OTHER IMPACTS      WASTE PROCESSING    TRANSP   DISPOSAL   LT CARE   .100 .090
                   GENERAT  DISPOSAL
COST ($)          5.80E+08  3.63E+07  2.29E+08  2.00E+08  1.61E+07
UNIT COST ($/M3)  8.31E+02  5.20E+01  3.29E+02  2.86E+02  2.31E+01
POP DOSE (MREM)      0.        0.     7.03E+05     0.
OCC DOSE (MREM)   3.91E+06  1.25E+05  6.49E+06  2.93E+06
LAND USE (M**2)      0.        0.        0.     2.46E+05
ENERGY USE (GAL)  1.73E+07  4.42E+05  1.65E+07  1.24E+06
```

disposal technology parameters are calculated for 1 million m^3 of waste disposed in the facility. For these two codes the basic data matrices BAS and ISPC are not utilized. The waste form parameters, however, are input into the calculation through the array ISPC, and the disposal technology indices are input through the IRDC array.

The major option available in the running of these codes is to set dose limitation criteria to different sets of values. In addition, INVERSI code calculates and prints the results of all seven distinct waste classification tests -- i.e., regular standard test at IIC years, regular modified test at IIC years, layered standard test at IIC years, layered modified test at IIC years, hot waste facility test at IIC years, regular standard test at 500 years, and regular standard test at 1000 years (see Section 3.4.4). INVERSW code also performs two sensitivity analyses: (1) it varies the percolation value associated with the given region index IR by assuming 50 percent of the value given, the value given, and twice the value given, and (2) it varies the retardation characteristics of the soils by calculating the limiting concentrations for all five sets of retardation coefficients considered in this work. These codes use a modified version of TAPE1 containing the pathway dose conversion factors and the environmental parameters associated with the given region index IR.

6.3 Basic Parameters of the Codes

Table 6.6 presents symbolic definitions of the data utilized in the analyses which have been presented in the previous chapters. Also given are the computer code definitions of most of the parameters, and some of the assumed values for the analyses.

Almost all the codes use two data tapes (some do not need to use all the information contained in these tapes) for input information: TAPE1 contains waste spectrum-independent information such as radionuclide concentrations of unprocessed waste, radionuclide specific

TABLE 6-6 : General Data Definitions

CONTROL INTEGERS AND VALUES (Read From Tape 1)

NSTR : Number of Waste Streams - 36
Individual streams are usually denoted by ISTR.

NNUC : Number of Radionuclides - 23
Individual nuclides are usually denoted by INUC.

FICRP(7) : This array, which is located in the BAST Common Block and read from Tape 1, contains ICRP body equivalent factors for the seven human organs being considered in the analysis. The values are 1.0, 0.12, 0.06, 0.03, 0.06, 0.12, and 0.06 for total body, bone, liver, thyroid, kidney, lung, and GI tract, respectively.

WASTE STREAM DEPENDENT ARRAYS

BAS(36,32) : Basic Data Matrix
Location : BAST Common Block
Read From : Tape 1

This matrix contains most of the waste stream dependent basic information. The first index of this array refers to the 36 waste streams assumed for the analysis. The second index refers to the following:

Index	Description
1	Waste Stream Name - Alphanumeric.
2	Reserved.
3	When input, it is the basic volume of the waste stream in m^3 generated between 1980 and 2000 for the entire country. This is replaced with the normalized disposed waste volume in subroutine COMBYN. For waste spectrum 1, the sum of this value over all streams is one million m^3. For other waste spectra it is referenced to spectrum 1.

TABLE 6-6 : (continued)

4	Gross undecayed activity of the untreated waste (Ci/m^3). This value is used only in transportation calculations, it is not modified in the program.
5-27	Radionuclide concentrations of the waste stream (in DATAD file, decayed to year 2000) for the 23 radionuclides in the stream (Ci/m^3). These concentrations are modified by volume reduction and increase factors (if applicable) and stored on top of the old concentrations in subroutine COMBYN.
28	Transported waste volume in m^3 which is calculated in subroutine COMBYN. Depending on where the waste processing takes place, this value may be different from the disposed waste volume, i.e., BAS(ISTR,3).
29-32	Waste processing impacts: costs ($), occupational dose (mrem), energy use (gallons of fuel), and population dose (mrem), respectively, for the waste stream volume given in BAS(ISTR,3). These impacts are calculated in subroutine COMBYN.

ISPC(36,11) : Waste Spectrum Matrix
Location : BAST Common Block
Read From : Tape 2

This matrix is read for each waste spectrum and contains all the information that distinguishes waste spectra from each other. The first index of the matrix refers to the 36 waste streams. The second index refers to the following:

Index	Description
1	Waste Packaging Index, which is used in the transportation calculations, and is composed of two digits representing packaging characteristics and the gamma emission characteristics of waste.

TABLE 6-6 : (continued)

2 Volume Reduction Factor multiplied by 100 (to make it an integer).

3 Volume Increase Factor similarly multiplied by 100.

4 Flammability Index - I4

5 Dispersibility Index - I5

6 Leachability Index - I6

7 Chemical Content Index - I7

8 Stability Index - I8

9 Accessibility Index - I9

10 Overall Waste Processing Index (I10) (see Section G.5) which is composed of four processing indices (digits) that are unscrambled and utilized in subroutine COMBYN to calculate BAS(ISTR,29) through BAS(ISTR,32).

11 Waste Disposal Status Index (I11) (see Section G.3) which is computed in subroutine RCLAIM.

RADIONUCLIDE DEPENDENT ARRAYS

DCF(23,7,8) : Pathway Dose Conversion Factor Matrix
Location : BAST Common Block
Read From : Tape 1

This matrix contains the multiple pathway dose conversion factors calculated through the CODE DOSE (see reference 2). DCF(I,J,K) is the pathway dose conversion factor for the radionuclide (I), human organ (J), and multiple pathway (K). Human organs considered (as given for the FICRP array) are total body, bone, liver, thyroid, kidney, lung, and GI tract, respectively. Multiple pathways considered are those resulting from the following release scenarios: accident, construction (air uptake pathway), agriculture (air uptake pathway), agriculture (food (soil) uptake pathway), direct-gamma (volume) exposure), well water, open water, and air.(2) This matrix is not modified by the code.

TABLE 6-6 : (continued)

NUC(23) : Radionuclide Names
Location : NUCS Common Block
Read From : Tape 1

This array contains the alphanumeric names of the radionuclides: H-3, C-14, FE-55, NI-59, CO-60, NI-63, SR-90, NB-94, TC-99, I-129, CS-135, CS-137, U-235, U-238, NP-237, PU-238, PU-239/240, PU-241, PU-242, AM-241, AM-243, CM-243, CM-244.

AL(23) : Decay Constants
Location : NUCS Common Block
Read From : Tape 1

This array contains the decay constants of the 23 selected radionuclides in units of year^{-1}.

FMF(23) : Leachate Partition Ratios
Location : NUCS Common Block
Read From : Tape 1

This array contains the radionuclide-dependent partition ratios between the radionuclide concentrations in the trench leachate and in the unsolidified waste obtained from Maxey Flats and West Valley experimental trench concentration data (see Appendix A).

RET(23,5) : Retardation Coefficients
Location : NUCS Common Block
Read From : Tape 1

This array contains the retardation coefficients of the radionuclides for five different soil conditions (see Appendix A). Only RET(I,1) and RET(I,4) are read in from Tape 1, the rest of the coefficients are calculated from RET(I,1) and RET(I,4) and stored in subroutine COMBYN.

TABLE 6-6 : (continued)

ENVIRONMENT DEPENDENT ARRAYS

Most of the codes utilized provide for six different disposal environments, each of which is denoted by a specific value of IR in the discussion below. The first four cases correspond to the regional characteristics outlined in Appendix C: northeast, southeast, midwest, and southwest. For most of the analysis only the second set of environmental parameters (IR=2), which represent the reference disposal facility environment, is utilized. The fifth and sixth sets of environmental parameters (IR=5 and IR=6) are variations of the reference facility environment and are utilized for the groundwater migration analyses.

FSC(6) : Construction Dust Mobilization Factor
Location : DTIS Common Block
Read From : Tape 1

This array (denoting f_s-construction) contains the dust mobilization factor, which depends on environmental parameters such as antecedent moisture conditions, soil particle size distribution, and annual average wind speed, for the air uptake pathway of the intruder-construction scenario.

FSA(6) : Agriculture Dust Mobilization Factor
Location : DTIS Common Block
Read From : Tape 1

This array (denoting f_s-agriculture) contains the dust mobilization factor, which depends on environmental parameters such as antecedent moisture conditions, soil particle size distribution, and annual average wind speed, for the air uptake pathway of the intruder-agriculture scenario.

TABLE 6-6 : (continued)

PRC(6,2) : Percolation Matrix
Location : DTIS Common Block
Read From : Tape 1

This matrix contains the potential infiltration into the disposal cells modified by the anticipated waste-water contact time given in units of meters for two different conditions: PRC(IR,1) is the no special cover condition, and PRC(IR,2) is the thick cover condition. These percolation values are given in Appendix C.

QFC(6,3) : Dilution Factors
Location : DTIS Common Block
Read From : Tape 1

This array contains the dilution factors (Q) in units of (m^3/year) for three groundwater discharge locations: boundary-well, population-well, and population-surface water discharge locations.

TTM(6,3) : Groundwater Travel Time Matrix
Location : DTIS Common Block
Read From : Tape 1

This matrix contains the groundwater travel times in years (t_w) between the sector of the disposal site (see Section 3.6) closest to the discharge locations and the three groundwater discharge locations mentioned above in QFC(6,3).

TPC(6,3) : Peclet Number Matrix
Location : DTIS Common Block
Read From : Tape 1

This array contains the dimensionless Peclet Numbers (P) for the groundwater travel times given by the above matrix TTM(6,3).

TABLE 6-6 : (continued)

RGF(6,3) : Geometric Migration Reduction Factor
Location : DTIS Common Block
Read From : Tape 1

This matrix contains the geometric reduction factor (r_g) resulting from the transverse relationship of the discharge location and the disposal facility for the three groundwater discharge locations considered in the analysis. These values are assumed to be unity for all three locations in the reference disposal facility case.

POP(6,3) : Exposed Waste Site Selection Factors
Location : DTIS Common Block
Read From : Tape 1

This matrix contains the exposed waste site selection factors (f_s): POP(IR,1) and POP(IR,2), in units of person-m^3/year, corresponding to the factors for the exposed waste-intruder-air and exposed waste-erosion-air scenarios, respectively, and POP(IR,3) corresponds to the exposed waste-surface water (intruder and erosion) scenarios.

DTTM(6) : Incremental Travel Times
Location : DTIS Common Block
Read From : Tape 1

This matrix contains the incremental travel times between the sectors of the disposal facility in units of years (see Section 3.6).

DTPC(6) : Incremental Peclet Numbers
Location : DTIS Common Block
Read From : Tape 1

This matrix contains the incremental Peclet numbers between the sectors of the disposal facility (see Section 3.5 and Appendix A).

TABLE 6-6 : (continued)

TPO(6,2) : Atmospheric Dispersion Factor Array
Location : DTIS Common Block
Read From : Tape 1

This array contains the atmospheric dispersion factors utilized in the accident scenarios for the regional disposal facility site considered. These factors have units of person-year/m^3 and are the atmospheric (X/Q) factors for a given radial distance multiplied by the population at that distance summed over all distances. TPO(IR,1) is for the accident-fire scenario, and TPO(IR,2) is for the single-container accident scenario.

NRET(6) : Retardation Status Array
Location : DTIS Common Block
Read From : Tape 1

The values in this array indicates the condition of the soils in the vicinity of the disposal site with regards to the retardation of radionuclides. It determines which RET(23,5) will be used in the groundwater migration analysis, i.e., RET(23,NRET(IR)).

parameters, and environmental parameters; and TAPE2 contains information on the waste spectrum being considered (e.g., volume reduction and increase factors, and waste form behavior indices). In addition, INPUT (query by the code at the terminal the code is being run from) is utilized for reading in the disposal technology indices and descriptive "header" information.

Computer printouts for the following programs and data files can be found in Appendix D:

Computer Programs:

INTRUDE
GRWATER
OPTIONS
INVERSI
INVERSW

Data Files:

DATA
DATAD
NUCS
SPC1
SPC2
SPC3
SPC4

REFERENCES FOR CHAPTER 6.0

1. Wild, R., et.al., Dames & Moore, "Data Base for Radioactive Waste Management. Volume 2. Waste Source Options," USNRC Report NUREG/CR-1759, November 1981.

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APPENDIX A

TRANSFER FACTORS

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APPENDIX A: TRANSFER FACTORS

This appendix considers the numerous radionuclide release/transport transfer factors between the various biota access locations defined and utilized in the pathway analyses. It also presents formulae and data with which they can be computed, and gives the transfer factor values that are utilized in the impact analyses.

A diagram showing the interactions of the biota access locations and the primary mechanisms through which they are connected is provided in Figure A.1. Also given in the figure are the sections of this appendix in which the transfer factors are considered. The term "multiple factor" implies that the transfer factor can be obtained by the multiplication of other transfer factors already being considered. For example, air (onsite) to soil (offsite) requires the multiplication of the air-to-air (Section A.3.1) and air-to-soil (Section A.3.2) transfer factors.

Various soil-to-air transfer factors, which will be utilized in the intruder (construction and agriculture) and the accident scenarios, are considered in Section A.1. Also given in Section A.1 is the wind initiated soil-to-air transfer factor, which is utilized in the exposed-waste scenarios. The waste-to-leachate, leachate-to-water, and soil-to-water transfer factors, which are applicable to groundwater and surface water scenarios, are considered in Section A.2. Other transfer factors are presented in Section A.3.

A.1 Soil-to-Air Transfer Factor

The soil to air transfer factor (T_{sa}) depends on many factors such as the moisture content and grain size distribution of the soil, the degree of atmospheric turbulence, the exposure period fraction, and the type of human activity, if any, affecting the soil. The magnitude

TO FROM	AIR (ON-SITE)	AIR (OFF-SITE)	SOIL (OFF-SITE)	WELL WATER	OPEN WATER
SOIL-WASTE (ON-SITE)	SUSPENSION (A.1)	MULTIPLE (A.1.4)	MULTIPLE	GROUNDWATER MIGRATION (A.2)	WATER TRANSPORT (A.2)
AIR (ON-SITE)	X	METEOROLOGICAL DISPERSION (A.3.1)	MULTIPLE	X	MULTIPLE
AIR (ON-SITE)	X	X	DEPOSITION (A.3.2)	X	DEPOSITION (A.3.2)
SOIL (OFF-SITE)	X	SUSPENSION (A.1)	X	GROUNDWATER MIGRATION (A.2)	WATER TRANSPORT (A.2)
WATER	X	X	IRRIGATION (A.3.3)	X	X

TRANSFER MECHANISMS
BETWEEN THE BIOTA ACCESS LOCATIONS

FIGURE A.1

DAMES & MOORE

of the exposure period fraction, which is the fraction of a year that the transfer factor is applicable, depends primarily on the activity or the transfer agent initiating the specific scenario such as wind, human intrusion, etc.

After a background section on the assumptions and major parameters influencing soil-to-air radionuclide transfer, the factor (T_{sa}) is examined in several sections that address the following different transfer activities or agents: construction, vehicular traffic, agriculture, and finally wind.

A.1.1 Background

In this appendix, the designations "transportable particulates" and "respirable particulates" are used as part of the procedures to calculate the soil-to-air transfer factor. Transportable particulates are usually defined as those with a mean aerodynamic diameter (MAD) less than 30 µm and they include respirable particulates. Transportable particulates must be considered if offsite wind transport of airborne radioactivity is considered -- i.e., non-respirable particulates may contribute to uptake pathways other than inhalation through transfer mechanisms such as deposition, dissolution, and plant uptake. The definition of respirable particulates may differ.(1,2) However, the particulates that are entrapped in the nasopharyngeal region (the upper part of the respiratory track) are usually particles with a MAD above 5 µm. Below this MAD the particles may reach the trachea bronchial and bronchiolar regions (i.e., the lung).(2) In this appendix, the upper bound for transportable and respirable particulates are assumed to be 30 µm and 10 µm, respectively.

There are several different types of techniques which may be used to calculate soil-to-air transfer of radionuclides. These calculational techniques are sometimes referred to as resuspension modelling. An extensive treatment of the resuspension of soils by various types of driving mechanisms such as wind-driven resuspension, mechanical resuspension, and local resuspension can be found in reference 3. This reference identifies three major types of resuspension modelling: (1) the resuspension factor with units usually stated as m^{-1}, which is defined as the ratio of the airborne concentration at a reference height to the quantity of contaminant on the surface of the ground; (2) the resuspension rate with units usually stated as sec^{-1}, which may be defined as the fraction of a contaminant present on the ground that is resuspended per unit time by either winds or mechanical disturbance; and (3) the mass loading concept, which gives the mass of soil particulates in air in units of g/m^3.

The specific technique utilized depends on the system being simulated. For average conditions, where very large areas for long periods of time may be involved, either the resuspension factor or the mass loading concept (both of which attempt to by-pass the details of the soil characteristics) may be used. For example, to calculate pathway dose conversion factors (see Appendix B) involving secondary biota access locations for chronic exposure conditions, the resuspension factor has been utilized. However, soil-to-air transfer factors calculated in this section strongly depend on the exposed waste area, duration of exposure, and the human activity initiating the exposure scenario. In these cases, resuspension rates turn out to be more convenient to use. For example, they can be used to describe concentrations at any point around a non-uniform contaminated area by the use of point source dispersion and deposition equations and integration over the area.(3) In any case, the resuspension factor and mass loading data are compared with the results from resuspension rate calculations where applicable.

In this appendix, the resuspension rate of transportable particulates will be denoted by E and will be expressed in units of $(g/m^2\text{-sec})$. This form of the resuspension rate is also referred to as the resuspension flux and can be converted to other forms of resuspension rate in a straightforward manner.(3) Mass loading and resuspension factors are also very easy to calculate from the resuspension flux as discussed in the sections below.

A.1.2 Construction

An inadvertant intruder may choose to excavate or construct on a disposal site. Under these circumstances, dust will be generated from the application of mechanical forces to the surface materials (soil, rock) through implements (wheels, blades) that pulverize and abrade these materials. The dust particulates generated are entrained by localized turbulent air currents. These suspended particles are thus available for inhalation by the intruder and for transport offsite by the wind.

The soil-to-air transfer factor (T_{sa}) may be expressed in terms of the geometry of the problem, the resuspension flux (E), and the following empirical equation:

$$T_{sa} = E \times f_r \times G /(u \times d), \text{ in } m^3 \text{ of soil per } m^3 \text{ of air} \qquad \text{(A-1)}$$

where:

E = suspension rate of transportable (<30 μm) particulates in units of (g/m^2-sec)

f_r = fraction of suspended transportable particulates that are respirable (<10 um).

G = Geometry Factor = $\dfrac{\text{Area subject to dusting}}{\text{Width of Area x Mixing height}}$

u = wind speed (m/sec)

d = density of the soil (g/m^3)

In this appendix, a base suspension flux is first calculated and then a correction factor is applied for site-specific environmental characteristics. The base suspension flux (E_0) is assumed to be 1.2 tons of transportable dust suspended per acre per month of heavy construction activity.(4) This figure is an average of many measured values and is applicable to construction operations with:

(1) Medium activity level (apartment or shopping center)
(2) Moderate silt (soil particles <75 μm in diameter) content (about 30%).
(3) Semi-arid climate (PE Index = 50).

The PE index is the Thornthwaite Precipitation-Evaporation index that is indicative of the antecedent moisture conditions of the soil and is commonly utilized to differentiate between the dusting potential of soils in different climatic division. The PE index is presented in Figure A.2 for the conterminous 48 states.(5) Based on the value of 1.2 tons/acre-month and an assumed 173 hours of activity per month (2080 hrs/12) yields a value for E_0 of 0.432 mg/m^2-sec.

Test data is not sufficient to derive the dependence of dust emissions on site-specific correction parameters such as silt content and climate. However, based on agricultural tilling considerations (see Section A.1.3) the following equation may be utilized to determine suspension flux E:(4)

$$E = E_0 \times (s/30) \times (50/PE)^2 \qquad \text{(A-2)}$$

where

$E_0 = 4.32 \times 10^{-4}$ g/m^2-sec

s = Silt content of surface soil, percent

PE = Thorthwaite's Precipitation-Evaporation index, which is dependent on the region considered (see Figure A.2)

FIGURE A-2

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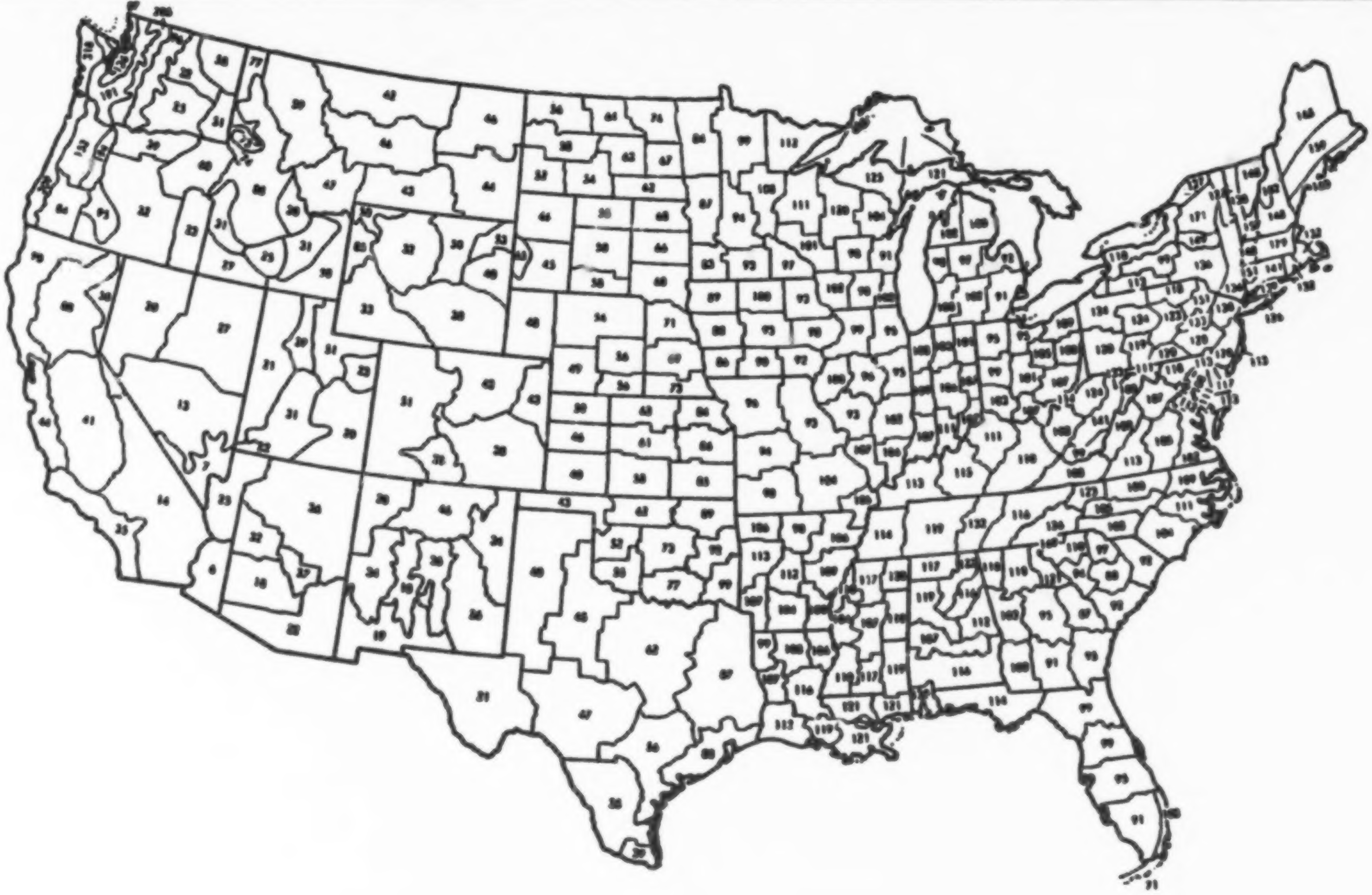


MAP OF THORNTHWAITE'S PRECIPITATION-EVAPORATION INDEX VALUES FOR STATE CLIMATIC DIVISIONS

SEE REPORT PB 275525, pg. 415

The geometry factor (G) can be calculated by assuming that the area of construction is 1000 m^2 (about a one-quarter acre lot) and that the mixing height is 3 meters. The area selected represents the size of a lot for a typical family dwelling or a small farm building complex with peripheral systems such as a barn, septic system, etc. The mixing height of 3 meters is a reasonably conservative value based on consideration of the height to which the construction dust may rise during a short time interval. The width of the area is best represented by the diameter of a circle whose area is about 1000 m^2. These assumptions yield G = 9.36.

The geometry factor is proportional to the square root of the area of construction. For example, for the intruder-construction scenario, an area of about 200 m^2 has been used. This area would yield a geometry factor of about 4.18. The above conservative value of 9.36 is used in this work for the intruder-construction scenario.

Wind speed varies with time and geographic location. However, a mean value of 4.5 m/sec (long-term annual average for the 48 conterminous states) may be utilized as an estimate of the average wind speed during the construction activity (assumed to require 3 months, or approximately 500 hours of dust-generating activity). Using these values yields:

$$(E_0G/u) = 0.90\times10^{-3}\ g/m^3$$

or 0.9 mg/m^3, which represents the transportable "dust loading" in the air -- i.e., the mass loading value.

Experimental determinations of respirable mass loading in the air in and around heavy construction equipment have been performed for surface coal mining operations. These experimental determinations indicate a variation in the respirable dust loading ranging from 0.56 mg/m^3 (for a bulldozer) to 6.7 mg/m^3 (for a front end loader) within a few feet of the equipment.(6) Respirable dust loading inside the cab of the equipment was a maximum of 1.8 mg/m^3 for the measurements taken. Ambient mass loading data for 1966 from the National Air Surveillance Network showed the average for urban stations ranged from 0.033 mg/m^3 to 0.254 mg/m^3, and a mean for nonurban locations of 0.038 mg/m^3.(3)

In this work, a combination of the above equations is utilized. The regional dependence of the soil-to-air transfer factor may be quantified through: (1) the wind speed (u), (2) the soil silt content (s), and (3) the PE index. Utilizing a soils density of 1.6 g/cm^3, and an arbitrary reference wind speed of 10 m/sec, the following equation may be derived from equations (A-1) and (A-2):

$$(T_{sa}) = (T_{sa})_0 \times f_r \times (10/u) \times (s/30) \times (50/PE)^2 \qquad \text{(A-3)}$$

where $(T_{sa})_o$ is the value of the base transfer factor, 2.53×10^{-10}, u is the mean wind speed in m/sec, f_r is the fraction of transportable particulates that are respirable (usually assumed to be unity), s is the soils silt content in percent, and PE is the precipitation-evaporation index defined before. The value of $(T_{sa})_o$ is obtained from equation A-1 assuming $E = E_o = 0.432$ mg/m^3, $f_r = 1$, $G = 9.36$, $u = 10$ m/sec, and $d = 1.6$ g/m^3.

Application of the reference disposal facility conditions (see Appendix C) of $s = 50$, $PE = 91$, and $u = 3.61$ m/sec and $f_r = 1$ yields a value of 0.218 mg/m^2-sec for E (which is used in the exposed waste scenarios), and a value of:

$$T_{sa} = 3.53 \times 10^{-10}$$

When this value is multiplied by the above assumed soils density of 1.6 g/cm^3, it yields a value of 0.565 mg/m^3 as the construction mass loading under the environmental conditions at the reference disposal facility.

A.1.3 Other Activities

This section examines two activities other than construction that also generate dust and could be used to calculate the transportable dust suspension rate (E): dust generated by a vehicle travelling on an unpaved road, and agricultural tilling.

Unpaved Roads

Vehicular traffic on unpaved roads results in fugitive dust emissions. For four wheeled vehicles, this dust generation rate may be estimated from the following empirical equation (within ± 20%):(4)

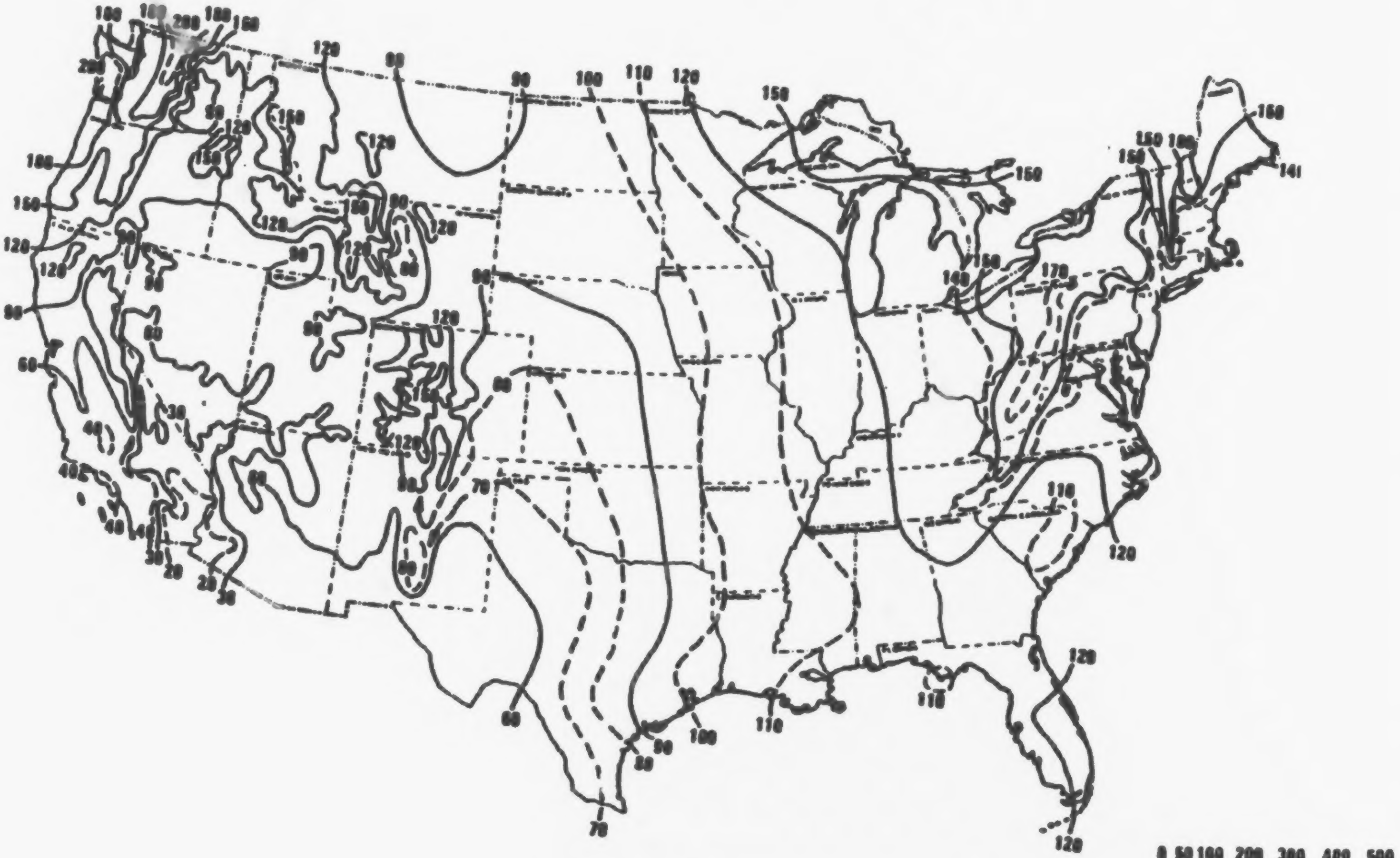
$$D = 0.49 \times V \times (s/30) \times [(365-w)/365] \qquad \text{(A-4)}$$

where:

- D = suspension rate of transportable dust, in pounds per vehicle mile
- V = Average vehicle speed, miles per hour
- s = silt content of the road surface material, percent
- w = mean annual number of days with 0.01 inch or more of rainfall (see Figure A.3).

This equation is estimated to be valid for vehicle speeds in the range of 30-50 miles/hour.(4) Based on the values of 30% silt content, a vehicle speed of 30 mi/hr, w = 100 days, and assuming a vehicle width of 3 meters and a mixing height of 3 meters, a mass loading factor of 0.334 g/m^3 is calculated.

This value is considerably more than the value of 0.565 mg/m^3 calculated for the construction case. A meaningful average may be obtained from this value, however, by assuming that exposure of the individual to this peak concentration lasts about 30 seconds. It is unreasonable to assume that the individual would remain in the vehicle dust cloud



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MILES

MEAN NUMBER OF DAYS WITH 0.01 INCHES OR MORE
OF PRECIPITATION IN UNITED STATES

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FIGURE A-3

A-11

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for more than a few seconds. Further assuming that during a period of 500 hours (comparable to the construction duration) he is exposed to the maximum concentration of dust from 70 vehicles (about one vehicle per working day), yields an average exposure mass loading of about 0.390 mg/m^3.

Agricultural Tilling

Many operations are performed to cultivate crops. Among these operations, the largest producer of suspended dust is tilling. Tilling produces a soil structure suitable as a crop seedbed and also eliminates weeds. The primary tilling method is plowing, which cuts, granulates and inverts the soil. Dust is generated as the loosened soil drops to the surface.

In addition to the equipment utilized, dust emissions from tilling depend on the surface soil texture (0-10 cm depth) and moisture content. Soil texture is characterized by the silt content, which is defined by the U.S. Department of Agriculture as particles between 2 um and 50 um in diameter. This is a slightly different definition from the one used to characterize construction site soil. The difference merely indicates that different field measurement schemes were used and is of little importance. Soil moisture is again characterized by the PE index (see Figure A.2).

Airborne radionuclide concentrations resulting from tillage can be calculated using equation (A-1). The only difference is that the suspension rate for transportable dust must be modified to reflect dust generation by tillage. The following empirical equation can be used to estimate the resuspension rate (E):(4)

$$K = 1.4 \times s \times f_{tr} \times (50/PE)^2 \tag{A-5}$$

where:

K = suspension rate for transportable dust (less than 30 µm), in pounds per acre tilled

s = silt content of the surface soil (2 µm to 50 µm), in percent

PE = Thornthwaite's PE index (see Figure A.2)

f_{tr} = fraction of suspended particulates (less than 60 µm) that is transportable (less than 30 µm).

The above resuspension flux (K) is not equal to (E) (different units and base conditions), but it can be used to estimate (E). For conditions similar to those specified for the construction scenario -- i.e., s = 30, PE = 50 -- and a typical value for f_{tr} of 80%, equation (A-5) yields a value of K = 34 pounds/acre per tilling event. This value is equivalent to a dust mobilization of 3.81 g/m^2 per tilling event. The time during which this suspension rate is applicable (necessary in order to determine the resuspension flux) is not specified since the measured dust mobilization rates are based on a single plowing event. It is assumed, however, that the tillage rate for a tractor is approximately 8-10 km/h. Using 10 km/h, and an effective plowing width for the tractor of three meters, the land is tilled at the rate of 8.33 m^2/s. Thus, in one second 31 grams of transportable dust is suspended. This value results in a mass loading of 1.3 g/m^3, if mixed uniformly with air to a height of three meters. The respirable fraction is unknown, but is conservatively assumed to be equal to one.

This calculated mass loading value would be applicable to the tractor operator. However, it is not consistent with the measured values for a bulldozer (0.565 mg/m^3) or a front end loader (6.7 mg/m^3) (see above). It is likely that most of the mobilized dust deposits within a few seconds of mobilization in close proximity of the tractor. Moreover, other parameters in above calculation (speed of the tractor, effective plowing width, and mixing height) are likely to be conservative.

The concentration of dust at a biota access point is more difficult to estimate. However, the mass loading for an observer standing on the downwind side of a 100 acre site, who will be exposed to a dust-laden air parcel only a small percentage of the time, is considered below using the above calculated dust mobilization rate.

A three meter wide air parcel (width of the tractor) passes the observer in 0.67 seconds in a 4.5 m/s wind. A square 100 acre site requires 212 3-meter-wide swaths to plow the field completely, thus exposing the observer to maximum dust concentration for a total of 140 seconds. Averaging this over the total time required to plow the field (13.5 hours) results in an average concentration at the access point of 3.75 mg/m^3. This does not account for dilution resulting from dispersion.

The respirable particulate concentration calculated for tillage is about 6.7 times that for construction. Assuming that a construction event takes three months (about 500 working hours) and an agricultural season involves 3 soil tilling events (13.5 hours per tilling of the 100 acre site), exposure to construction-generated dust would be 12.35 times the duration of exposure to tillage dust. Averaging the agriculture-generated dust loading over 500 hours yields an airborne concentration of 0.304 mg/m^3, which corresponds closely to the 500 hour construction scenario average of 0.565 mg/m^3, and is smaller than that associated with the unpaved road scenario.

A.1.4 Wind Suspension

The mechanism of mobilization of particulates from soil by wind depends on factors such as wind speed, soil properties such as silt and moisture content, and the nature of the surface. Wind action results in three basic modes of particle motion: surface creep (particles above 500 µm in size), saltation (particles between 100 µm and 500 µm in size), and airborne suspension (particles less than 100 µm in size).

This section considers the last mode of particle motion -- i.e., airborne suspension, which in general is a consequence of the saltation process. Many investigators have performed experimental and theoretical studies on airborne suspension.(7-12) A recent equation based on these studies will be utilized here. The suspension rate (E) for particulates less than 20 um in aerodynamic diameter is given by:(7)

$$E = 2 \times 10^{-6} \left(\frac{U}{U_o}\right)^2 \left(\frac{U}{U_o} - 1\right) \left[\left(\frac{U}{U_o}\right)^{p/3} - 1\right] \qquad \text{(A-6)}$$

where:

E = Suspension rate, in g/m^2-s,

U = shear velocity (m/s),

U_o = threshold velocity for saltation (m/s), and

p = mass percent of particles less than 20 um in aerodynamic diameter.

The sheer velocity, U, is given by the equation:(7)

U = wind speed at height (z) / [$2.5 \times \ln(z/z_o)$]

where z_o is the height at which the windspeed is equal to zero. Assuming a particle density of 2.4 g/cm^3, and an average particle diameter of 300 µm, typical of fine grained soils, the threshold velocity for saltation U_o can be calculated to yield(7)

$U_o = 0.29$ m/s

An average wind speed of 4.5 m/sec (long-term annual average of 48 conterminous states) measured 1 meter above the ground surface yields

$U = 0.39$ m/s

and the equation (A-6) reduces to

$$E = 1.22 \times 10^{-6} [(1.34)^{p/3} - 1] \text{ g/m}^2\text{-s} \qquad \text{(A-7)}$$

In general, (p) is a coefficient around a few percent. Assuming a value of 3 percent yields:

$$E = 4.1 \times 10^{-4} \text{ mg/m}^2\text{-s}$$

which is considerably less than the construction event value. This value of E will be utilized in the calculation of the wind transport waste form factor (f_{wi}) for the erosion-initiated exposed waste scenarios (see Section 3.7).

This value is conservative since it has been calculated using conditions applicable to an uranium mining environment.(7) It is likely to depend on site-specific conditions. However, due to the generic nature of this report, this conservative value is assumed to be applicable to all the sites considered.

This value is also likely to be very conservative for estimation of the erosion rate of the waste cover. The value is calculated based on granular soil and does not consider design measures such as a layer of gravel or rip rap which act to stabilize the ground surface, and prevent erosion from occurring.

Notwithstanding this, the above value for E can be used to estimate a conservative upper bound value for the wind erosion rate. Assuming a soil density of 1.6 g/cm^3, this suspension rate corresponds to an erosion rate of the waste cover of about 0.001 cm/yr.

A.2 Soil-to-Water Transfer Factors

This section considers the soil-to-water transfer factor T_{sw} for two specific scenarios: (1) the groundwater scenario for which the transfer factor is composed of two separate factors - waste-to-leachate and leachate-to-water at access point; and (2) the surface water transport scenario for which it quantifies the water mobilization of the surface sediments.

Of these two mechanisms only the groundwater scenario will be considered in detail. Surface water mobilization and transport of particulates from contaminated soil is briefly discussed in Section A.2.3. Erosion of soil by surface water is also treated in the same section.

A.2.1 Waste-to-Leachate Transfer Factor

The groundwater scenario postulates the following sequential events: (1) subsurface water (infiltrating rain water) contacts the waste; (2) radioactivity is dissolved by the water (leached from the disposed wastes); (3) water that is laden with dissolved radioactivity continues its downward movement through the subsurface strata (unsaturated zone) and reaches the saturated zone; (4) the water and dissolved radionuclides migrate horizontally through the saturated zone, in accordance with the dynamics of fluids in porous media; and (5) ultimately reach an access location, which can be a pumped well or a surface water body.

The first step above, infiltration, is considered in Section 3.6 and in reference 12. This section considers the second of the above steps. The last three steps are treated in Section A.2.2.

The most commonly utilized concept in the quantification of the waste-to-leachate transfer factor has been the "leach rate." This concept is a somewhat crude representation (necessitated by the complexity of the problem) of the amount or fraction of a given waste mass assumed to be mobilized per year by infiltrating water. There is significant variation in the behavior of leach rates for solidified waste forms and unsolidified waste forms. This variation results primarily from the fact that solidified waste contacts the leachate through a definable surface area, whereas the unsolidifed waste has no such surface. Moreover, radionuclides leach at different rates, depending on their chemistry. These concepts are considered in separate sections below.

Solidified Waste Leachability

The rate at which radionuclides leach from waste products generated by different nuclear related industries has been of increasing interest in recent years. An effort has been made in many experiments to vigorously identify the chemical and radiological characteristics of those wastes and to test for their leachabilities under the various solidification technologies presently available. The great variety of physical and chemical characteristics displayed by these waste products requires a large scale experimental effort to obtain the statistically comprehensive results one would ideally desire.

Although this experimental effort has only recently begun, there is a significant quantity of such experimental data available. This data has been of considerable use in building the leachability data base used in the study, both from the viewpoint of presenting actual experimental values, and of providing a better understanding of the theoretrial mechanisms behind leachability. This has resulted in refinements in choosing theoretical values where experimentation proved lacking.

Leachability is a measure of the ability of radionuclides to be removed from a solidified waste product upon contact with an aqueous solution. In the experimental data obtained, the leachability was most commonly sought for univalent, divalent, and trivalent radionuclides, most commonly represented by cesium, strontium, and cobalt, respectively. Investigations included waste forms solidified by agents such as vinyl ester styrene, cement, urea formaldehyde, bitumen, polyester, and polyethylene.

There is a large body of "leach rate" data from several nations using a variety of experimental methods.(13-15) Attempts at standardization of experimental methodology and reporting of information have only recently been initiated.(13) In this report, L(t), which is defined as the leached fraction of activity per year corrected for waste shape, is presented here as given in reference 13:

$$L(t) = [\sum a_n/A_o] \times [V/S] \tag{A-8}$$

where:

a_n = leached activity after (n) time periods
A_o = total activity in the waste
V = volume of the waste (m^3)
S = surface volume of the waste (m^2)

The experimental results are, for the most part, presented in the form of a graph with the absissa plotting time (t) and the ordinate recording L(t). The value (V/S) was employed in an effort to provide leach rate measurements which are independent of specimen size and geometry.

Data presented in this manner, following the recommended IAEA procedures, implies the use of the semi-infinite model from diffusion mass transport theory. When expressed in this manner, the fractional activity released for specimens of different sizes and geometries is determined by using the relation:

$$[\sum a_n/A_o]_1 \times [V/S]_1 = [\sum a_n/A_o]_1 \times [V/S]_2 \qquad \text{(A-9)}$$

It has been shown that the cumulative fraction leached from a sample, when plotted against time (t), is approximately linear for large t, but not very linear, in a number of cases, for small t. It was found that going beyond the linear to the fifth degree polynomial gave a better fit for the time period considered, in this case one hundred days. The resultant equation has the form:

$$L(t) = A_o + A_1 t^{0.5} + A_2 t + A_3 t^{1.5} + A_4 t^2 + A_5 t^{2.5} \qquad \text{(A-10)}$$

Although this equation gives a good fit to experimental data at times up to 100 days, the usual limit of experiments, it is not able to predict values of leach rate L(t) consistent with in-situ measurements of leachate concentrations. The values obtained after correcting for actual waste geometries using equation (A.2-2) are frequently above the upper bounds for unsolidified wastes derived from leaching data obtained from Maxey Flats disposal facility (see Section A.4.2).(15)

Such discrepancies are probably due to the very large number of independent parameters that affect leachability and that cannot all be controlled under simulated conditions. For example, the IAEA procedure specifies that distilled or deionized water be used as the leachant, that the ratio of the sample volume to surface ratio be about 10 cm, and that the entire leachate volume be replaced periodically. Moreover, there is no procedure to quantify the effects of partially saturated conditions, which are more likely to be mechanisms for leaching.

In this report, experimental leachate/waste concentration ratios derived in the following section for unsolidified wastes are utilized to estimate the leachability of solidified wastes. A correction factor derived from laboratory experiments, however, is applied to account for the lower leachability of solidified wastes.

Unsolidified Waste Leachability

In view of the variable physical and chemical characteristics of the waste,$^{(13-14)}$ the variable chemistry of the in-situ waste/soil mixture,$^{(15)}$ and the variability of long-term conditions (e.g., bacterial action), theoretical or experimental tools available to predict the leachability of unsolidified waste after it has been disposed of cannot be considered reliable. For the solidified case, at least the properties of the waste form (e.g., porosity, chemistry, etc.) can be predicted with some reasonable degree of confidence. However, for the unsolidified case, even this partial knowledge does not exist. Therefore, in this report, the leach rates from unsolidified waste streams are not calculated directly. Instead, a radionuclide specific average leach fraction is calculated which is the ratio, assuming totally saturated conditions, of the concentration of a radionuclide in the leachate to the concentration of the radionuclide in the waste. This leach fraction may then be multiplied by the fraction of a year that infiltrating water contacts the waste.

In this report, the average upper bounds of the unsolidified waste leach fraction, henceforth denoted by M_o, are estimated assuming that the leachate/waste conditions at the existing Maxey Flats and West Valley disposal facilities, can be used to approximate this fraction. The reason these facilities have been selected is because a considerable amount of data exists on these disposal sites and the trenches are known to have been inundated for a considerable number of years. Furthermore, a recent work$^{(36)}$ on Maxey Flats leachates has indicated that plutonium exists as a dissolved species (primarily as complexes of the tetravalent ion with strong organic ligands such as EDTA) and that the complexes are not sorbed well by sediment and are only partially precipitated by ferric hydroxide. Average radionuclide concentrations in the trench leachate$^{(18)}$ and in the disposed waste$^{(19)}$ for the Maxey Flats disposal facility for H-3, Co-60, Sr-90, Cs-137, Pu-238, Pu-239, and Am-241 are presented in Table A-1.

TABLE A.1 : Maxey Flats Leachate and Waste Concentrations

Location		H-3	Co-60	Sr-90	Cs-137	Pu-238	Pu-239	Am-241
Trench 1	Leachate*	3.70E6	2.70E2	--	1.90E2	--	--	1.70E2
462 m^3**	Waste***	2.08E4	3.10E3	--	1.12E6	--	--	2.12E4
Trench 2	Leachate	2.50E7	--	6.80E3	1.00E2	--	--	--
512 m^3	Waste	9.53E9	--	5.01E6	1.29E8	--	--	--
Trench 7	Leachate	4.40E8	2.50E3	2.00E6	4.60E3	--	--	--
983 m^3	Waste	5.97E7	9.32E8	2.84E7	4.12E7	--	--	--
Trench 18	Leachate	4.50E8	2.20E4	4.70E4	4.90E3	--	5.10E1	2.00E1
1873 m^3	Waste	5.61E8	4.08E9	1.84E8	4.99E8	--	5.61E4	2.10E3
Trench 19S	Leachate	6.90E7	2.50E3	2.90E5	1.00E4	2.10E5	2.10E4	1.50E3
2637 m^3	Waste	1.07E9	5.80E9	6.90E7	4.40E7	6.86E6	4.82E7	2.18E5
Trench 26	Leachate	2.00E8	1.40E3	3.50E4	7.50E3	1.30E5	3.50E3	1.00E3
2578 m^3	Waste	4.19E8	2.97E7	1.08E6	2.09E8	2.32E7	2.73E7	1.96E6
Trench 27	Leachate	5.90E8	2.00E4	2.10E5	2.30E4	1.30E3	--	1.50E4
6353 m^3	Waste	3.98E8	1.37E7	8.72E6	4.91E6	1.89E7	--	3.81E5
Trench 31	Leachate	4.70E9	3.60E3	--	4.00E4	--	--	7.00E2
7945 m^3	Waste	6.09E10	2.28E8	--	1.56E7	--	--	2.48E5
Trench 32	Leachate	2.30E9	6.00E3	5.40E5	6.00E3	1.10E5	2.90E3	4.00E1
8438 m^3	Waste	1.41E8	4.03E8	4.80E6	2.35E7	1.43E9	5.91E7	6.54E5
Trench 37	Leachate	1.10E7	5.00E4	--	9.80E3	--	--	2.80E4
1026 m^3	Waste	4.32E5	1.96E6	--	2.83E6	--	--	6.30E5

---

* Leachate data in (pCi/l) from reference 18.

** Waste volume data from reference 21.

*** Waste concentrations in (pCi/l) from inventory given in reference 19.

To calculate the average waste concentrations, the fraction of the waste labeled "mixed fission products" or "unidentified radionuclides" have been conservatively ignored. For cobalt, several of the ratios are unrepresentatively low, and have been conservatively discarded assuming that they represent disposal trenches containing a significant amount of sealed sources. The remaining ratios have been geometrically-averaged to obtain the leachate-to-waste concentration ratios presented in Table A-2.

For tritium, the ratio turned out to be higher than unity; this value is reasonable considering the relative mobility of tritium. For example, if 250 cm^3 of water contacted 1000 cm^3 of waste with an effective porosity of 0.25 and leached all the tritium, this ratio would have been 4.0. Furthermore, if the same leachate contacted other unleached waste and leached some more H-3, the ratio would be even higher.

For carbon-14 and uranium-238, Maxey Flats trench leachate data is not sufficient for a similar calculation. For these nuclides, leachate data obtained from the West Valley disposal facility is used.(20) However, U-238 concentrations in West Valley waste could not be determined from the existing information. For U-238, waste concentration data from the Maxey Flats disposal facility is conservatively used to obtain the ratios. These data and calculations are presented in Table A-3.

These calculated ratios have also been used to estimate M_0 for other radionuclides for which the data is insufficient to calculate similar ratios. It is assumed that the iodine and the technetium values are 10 percent of the tritium value, that nickel and iron are chemically similar to cobalt, that the niobium value is 75% of the cobalt value, and that neptunium and curium are chemically similar to plutonium. The resulting ratios utilized in the impact calculations are presented in Table 3-8.

TABLE A.2 : Maxey Flats Leachate/Waste Ratios and Averages

Location	H-3	Co-60	Sr-90	Cs-137	Pu-238	Pu-239	Am-241
Trench 1	1.77E+2	8.70E-2	--	1.69E-4	--	--	8.02E-3
Trench 1S	2.62E-3	--	1.36E-3	7.75E-7	--	--	--
Trench 7	7.37E+0	2.68E-6*	7.04E-2	1.12E-4	--	--	--
Trench 18	8.02E-1	5.39E-6*	2.55E-4	9.82E-6	--	9.09E-4	9.52E-3
Trench 19S	6.45E-2	4.31E-7*	4.20E-3	2.27E-4	3.06E-2	4.36E-4	6.88E-3
Trench 26	4.77E-1	4.71E-5*	3.24E-2	3.59E-5	5.60E-3	1.28E-4	5.10E-4
Trench 27	1.48E+0	1.46E-3	2.41E-2	4.68E-3	6.88E-5	--	3.94E-2
Trench 31	7.72E-2	1.58E-5*	--	2.56E-3	--	--	2.82E-3
Trench 32	1.63E+1	1.48E-5*	1.13E-1	2.55E-4	7.69E-5	4.91E-5	6.12E-5
Trench 37	2.55E+1	2.55E-2	--	3.46E-3	--	--	4.44E-2
Average :	1.15	1.48E-2	9.86E-3	1.62E-4	**	4.67E-4	4.11E-3

---

* These low ratios were neglected, probably due to sealed sources.

** Pu-238 ratios were counted in the Pu-239 average.

TABLE A-3 . C-14 and U-238 Leachate/Waste[a] Concentration Ratios

	Leachate		Waste		
Nuclide	Trench	(µCi/ml)[b]	Volume (m³)	Inventory (Ci)	Ratio
C-14	WV 1-2	1.27E-6	4800	1	6.10E-3
	WV 3	1.16E-6	5626	5	1.31E-3
	WV 4	1.38E-6	7771	8	1.34E-3
	WV 5	3.91E-5	7890	3	1.03E-1
Averages					5.76E-3
			Trench	(µCi/ml)	
U-238	WV 1-2	2.48E-9	MF 7	1.63E-4	
	WV 3	1.47E-9	MF 18	1.06E-4	
	WV 4	5.77E-9	MF 19S	8.36E-5	
	WV 5	1.63E-7	MF 26	7.94E-6	
			MF 27	1.54E-5	
			MF 31	9.32E-5	
			MF 32	2.07E-4	
Averages		7.65E-9		6.11E-5	1.25E-4

(a) WV = West Valley Disposal Site, MF = Maxey Flats Disposal Site.

(b) Leachate concentrations are averages of several sumps.

(c) Source : References 18, 19, and 20.

The primary rationale for this approach is that under specified chemical conditions there is an upper limit to the solubility of all elements. Moreover, several investigators feel that the use of Maxey Flats leachate data is the best that can be done with the available experimental data.(3)

However, in order to use these calculated ratios, transient and partially saturated conditions likely to exist in properly designed trenches must be considered. It is unlikely that conditions existing in Maxey Flats or West Valley trenches will be permitted to develop in the future. Therefore, these ratios have been modified by the "contact time fraction", denoted by t_c, before application to groundwater migration calculations in this work.

Several time dependent leaching experiments on solidified waste samples have been performed.(14-16) The results of these experiments, however, appear not to be applicable to partially saturated conditions since all the experiments were performed with complete inundation of the samples. There is no data to indicate the behavior of leaching under partially saturated conditions. Assumption of linear dependence is one of the viable ways to approximate this behavior (first order approximation). The linear dependence assumption means that the above ratio should be multiplied by the fraction of time the wastes may be assumed to be in contact with water under fully saturated conditions. In other words, the factor t_c is estimated from the following formula (see Section 3.5.1):

$$t_c = p/(nv)$$

where p is the percolating water in meters/year that infiltrates and comes into contact with the waste, n is the effective porosity of the disposal cell, and v is the speed of the percolating water in meters per year. This equation means that the contact time fraction is the fraction of a year the percolating front (in a continuous mass) takes to pass through a horizontal plane in the disposal cell.

A.2.2 Groundwater Migration

A detailed groundwater migration model is described in reference 22. This reference considers both saturated and unsaturated zones and time dependent migration in three dimensions. One of the dimensions (longitudinal - in the direction of the hydraulic velocity) is treated exactly and the other two dimensions (transverse - perpendicular to the direction of the hydraulic velocity) are treated through an approximation called the "time-independent transverse dispersion" approximation. The models and equations presented in this reference, however, are too complicated for utilization in a generic study. Therefore, a simplified one-dimensional migration model is formulated and developed based on the formulae presented in reference 22.

A general geometry of the migration problem is presented in Figure A.4. The most significant concept presented in this figure is that the migration problem has been formulated in terms of the relationship of the fluxes at the source and at the access location, rather than concentrations. This formulation is easier to handle and more meaningful in terms of calculating impacts. Based on this figure the following relationship is applicable:

$$J(x,t) = r_g \, r_t \, J_o \tag{A-11}$$

where $J(x,t)$ and J_o are the radionuclide fluxes in units of Ci/year* at the discharge surface and the source, respectively, and r_g and r_t are dimensionless reduction factors. The reduction factor r_g expresses the reduction due to the geometrical relationship of the source and the access location, while r_t expresses the reduction due to migration and decay.

---

* The above definition of flux is sometimes referred to as the total flux, in addition, "flux" is sometimes given in units of Ci/m^2-year which is sometimes referred to as the differential flux. This report will refer to the above defined variable as the flux in units of Ci/year.

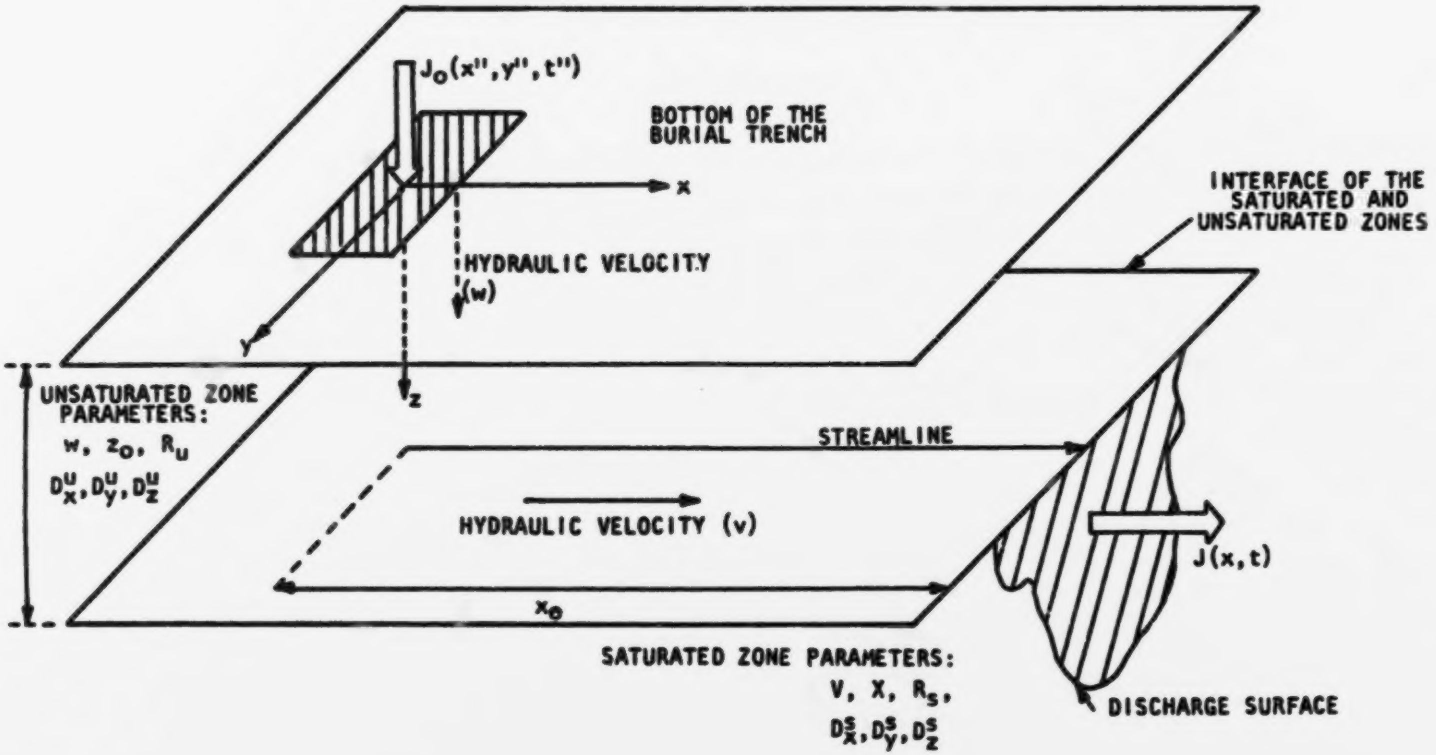

$J_o(x'', y'', t'')$
BOTTOM OF THE BURIAL TRENCH
x
INTERFACE OF THE SATURATED AND UNSATURATED ZONES
HYDRAULIC VELOCITY (w)
y
z
UNSATURATED ZONE PARAMETERS:
w, z_o, R_u
D_x^u, D_y^u, D_z^u
STREAMLINE
HYDRAULIC VELOCITY (v)
$J(x,t)$
x_o
SATURATED ZONE PARAMETERS:
$V, X, R_s,$
D_x^s, D_y^s, D_z^s
DISCHARGE SURFACE

FIGURE A.4

GEOMETRY OF GROUNDWATER MIGRATION

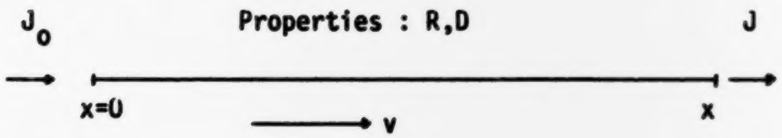
The factor r_g is time-independent and depends only on the geometrical relationship of the access location and the source. The factor r_t, however, depends both on space and time, including the duration of the source term, henceforth called T. The combined factor $(r_g r_t)$ quantifies the effects of the intervening medium between the source and the access location.

The time dependent concentration C(x,t) at the access location in terms of the flux is:

$$C(x,t) = J(x,t) / Q \qquad \text{(A-12)}$$

where (Q) is the dilution factor in units of volume/time. It may be the pumping rate of a well, or the flow rate of a river.

One-dimensional geometry is considered in this report to calculate the factors r_g and r_t. This geometry is presented below:



The general solution to this problem is obtained in reference 22 using a Green's Function approach.(23) Using this approach, first the solution of the problem for a unit delta function source term is obtained.(23) This solution (Green's Function of the problem) is given by the following expression:

$$F_g(x,t,t') = -\exp\left[-\lambda(t-t')+\frac{vx}{2D}\right]\frac{\partial}{\partial x}\left[\exp\left(\frac{vx}{2D}\right)\operatorname{erfc}\left[\frac{x+v(t-t')/R}{\sqrt{4D(t-t')/R}}\right]\right] \qquad \text{(A-13)}$$

Using this function, the flux $J(x,t)$ at any point and time can be calculated by evaluating the following expression:(22)

$$J(x,t) = \left(v - D\frac{\partial}{\partial x}\right) \int_0^t F_g(x,t,t')J_0(t')dt' \qquad \text{(A-14)}$$

In this report the source term, $J_0(t')$, is assumed to be given by the following:

$$J_0 = U(T-t')\ S_0 \exp(-\lambda t') \qquad \text{(A-15)}$$

where $U(t)$ is the unit impulse function that is unity for a positive argument and zero otherwise, and λ is the decay constant of the radionuclide. The expression given in the above equation (A-14) can be evaluated to yield:(22)

$$J(x,t) = S_0 \exp(-\lambda t)\ [F(t) - F(t-T)]\ , \qquad \text{(A-16)}$$

where:

$$F(t) = 0.5\ U(t)\ [\mathrm{erfc}(X_+) + \exp(P)\ \mathrm{erfc}(X_-)]\ , \qquad \text{(A-17)}$$

$$X_{\pm} = \frac{\sqrt{P_j}}{2}\ \frac{1 \pm t/(Rt_{wj})}{\sqrt{t/(Rt_{wj})}}\ , \text{ and} \qquad \text{(A-18)}$$

$$\mathrm{erfc}(x) = 1 - \int_0^x (2/\sqrt{\pi})\ \exp(-t^2)\ dt\ . \qquad \text{(A-19)}$$

This solution may be generalized for multiple dimensions or for heterogeneous media. Heterogeneous media implies time dependence of the variable x and time and space dependence of the variables v, D, and R. The following expressions may be used to obtain space and time independent parameters:(22)

$$\bar{x} = \frac{1}{T} \int_0^T x(t)dt \qquad \text{(A-20)}$$

$$\bar{v}(x) = \frac{1}{T} \int_0^T v(x,t)dt \qquad \text{(A-21)}$$

$$\frac{1}{[v]} = \frac{1}{X} \int_0^X \frac{dx}{\bar{v}(x)} \qquad \text{(A-22)}$$

$$[R] = \frac{[v]}{X} \int_0^X \frac{R(z)}{\bar{v}(x)} dx \qquad \text{(A-23)}$$

where $\bar{x}$, [v], and [R] represent time and space averaged parameters (the parameter D, the dispersion coefficient, is handled in a manner identical to v), and (x) and (t) are the space and time variables, respectively. The averaging is performed over a sufficiently long time (T) and sufficiently large space (X) to take into account all the significant variations of these parameters.

A.2.3 Percolation

The amount of water infiltrating through the trench covers and contacting the waste is a basic parameter required for the groundwater migration calculations. This section presents the assumptions utilized in this work.

There are several techniques for calculating the infiltrating component of precipitation (also called PERC in several references). One of these methods is the "water balance method" introduced by Thornthwaite(24) and developed by Fenn, et.al.(25) This method has been applied successfully to many site-specific problems.(22) However, one of the most crucial parameters in this calculation is the maximum soil moisture capacity (S_M). This parameter is primarily a function of the vegetation root zone thickness, and the amount of percolation decreases with increasing maximum soil moisture capacity. Moreover, this method does not explicitly consider the hydraulic properties of the substrata. Use of the water balance method also does not directly allow consideration of the effect of potential use of low-permeability barriers against infiltration (also termed "percolation barriers" or "moisture barriers").

Another possible technique to calculate PERC is the adoption of an unsaturated zone water transport model that considers the gravitational, capillary, osmotic and chemical potentials. In this report, primarily due to the generic nature of the work, it was decided to adopt a more practical approach in the determination of the percolation component.

For the cases where waste cover integrity cannot be assumed, which may be either due to waste form instability or simpler design measures such as a minimum cover over the waste or no trench stabilization program, water balance calculations will be utilized to determine the percolation component. Water-balance calculations typical of sites located in four different regions of the country (northeast, southeast, midwest, and southwest) are given in Tables A-4 and A-5. For the four regions of concern, these calculations lead to a percolation component of 74 mm for the northeast, 180 mm for the southeast, 50 mm for the midwest, and 0 mm for the southwestern locations (see Appendix C). However, for calculational purposes, a value of 1 mm is assumed for the southwestern location. These values are used in the impact analyses.

For the cases where there exists engineered trench covers including percolation barriers such as low permeability clay layers and where the integrity of these covers may be assumed (e.g., the wastes underneath are stable), it will be assumed that the percolation component is determined by the Darcy velocity of the least permeable stratum

TABLE A-4 : Water Balance Analysis Data and Assumptions

Legend: All units in (mm of water) except for C which is dimensionless.

S_M = Maximum Soil Moisture Storage
P = Precipitation
C = Surface Runoff Coefficient
R = Surface Runoff
I = Infiltration
PET = Potential Evapotranspiration
I-PET = Difference between (I) and (PET)
CNS = Cumulative sum of negative (I-PET)
S = Soil Moisture Storage
dS = Change in Soil Moisture Storage
AET = Actual Evapotranspiration
PERC = Percolation into Groundwater System

Assumptions:

P = Data from representative location(24)
PET = Data from representative location(24)
C = Estimated for each region based on soil description and reference 11.
S_M = For humid sites assumed 100 mm and for arid site assumed 50 mm.

Calculations: Follows in Table A-5.

TABLE A-5 : Detailed Water Balance Calculations

NORTHEAST REGION : S_M : 100 mm

	J	F	M	A	M	J	J	A	S	O	N	D
P	71	65	73	72	92	110	114	110	92	86	78	71
C	.20	.20	.20	.20	.15	.15	.15	.15	.15	.18	.20	.20
R	14	13	15	14	14	16	17	16	14	15	16	14
I	57	52	58	58	78	94	97	94	78	71	62	57
PET	0	0	0	28	77	111	129	110	75	38	6	0
I-PET	57	52	58	30	1	-17	-32	-16	3	33	56	57
CNS						-17	-49	-65				
S	214	266	324	100	100	84	60	51	54	87	100	157
dS	57	52	58	0	0	-14	-24	-9	3	33	13	57
AET	0	0	0	28	78	108	121	103	75	38	6	0
PERC	0	0	0	30	1	0	0	0	0	0	43	0

SOUTHEAST REGION : S_M : 100 mm

	J	F	M	A	M	J	J	A	S	O	N	D
P	80	100	96	84	82	102	149	147	103	64	77	81
C	.14	.14	.14	.14	.14	.12	.12	.12	.12	.12	.14	.14
R	11	14	13	12	11	12	18	18	12	8	11	11
I	69	86	83	72	71	90	131	129	91	56	66	70
PET	13	15	37	65	115	158	172	157	114	64	29	13
I-PET	56	71	46	7	-44	-68	-41	-28	-23	-8	37	57
CNS					-44	-112	-153	-181	-204	-212		
S	100	100	100	100	64	32	21	16	12	11	48	100
dS	0	0	0	0	-36	-32	-11	-5	-4	-1	37	52
AET	13	15	37	65	113	147	162	151	107	63	29	13
PERC	56	71	46	7	0	0	0	0	0	0	0	0

TABLE A-5 : (continued)

MIDWEST REGION : S_M : 100 mm

	J	F	M	A	M	J	J	A	S	O	N	D
P	21	23	36	73	108	108	94	91	101	64	33	25
C	.15	.15	.15	.15	.13	.10	.10	.10	.10	.13	.15	.15
R	3	3	5	11	14	11	9	9	10	8	5	4
I	18	20	31	62	94	97	85	82	91	56	28	21
PET	0	0	6	43	88	127	147	131	86	44	7	0
I-PET	18	20	25	19	6	-30	-62	-49	5	12	21	21
CNS						-30	-92	-141				
S	101	121	100	100	100	74	39	24	29	41	62	83
dS	18	20	0	0	0	-26	-35	-15	5	12	21	21
AET	0	0	6	43	88	123	120	97	86	44	7	0
PERC	0	0	25	19	6	0	0	0	0	0	0	0

SOUTHWEST REGION : S_M : 50 mm

	J	F	M	A	M	J	J	A	S	O	N	D
P	6	10	20	48	71	79	64	72	37	45	19	14
C	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
R	1	1	2	5	7	8	6	7	4	4	2	1
I	5	9	18	43	64	71	59	65	33	41	17	13
PET	1	4	21	47	86	129	154	136	95	49	15	0
I-PET	4	5	-3	-4	-22	-58	-95	-71	-62	-8	2	13
CNS			-3	-7	-29	-87	-182	-253	-315	-323		
S	20	25	23	20	14	8	3	1	1	1	3	16
dS	23	9	-2	-3	-6	-6	-5	-2	0	0	1	18
AET	1	4	20	46	70	76	64	67	95	41	15	13
PERC	0	0	0	0	0	0	0	0	0	0	0	0

between the waste and the atmosphere. The Darcy velocity of a material, with hydraulic conductivity (K) in units of m/yr and unit hydraulic gradient (the most conservative assumption), is equal to K m^3/m^2-yr. This number, however, should be modified by the fraction of each year during which there is at least 0.01 inch of precipitation. Therefore, (p) may be calculated from the following equation:

$$p = K\,(w/365) \qquad \text{(A-24)}$$

where (K) is the hydraulic conductivity of the least permeable layer between the atmosphere and the waste, and (w) is the mean annual number of days with 0.01 inch or more of rainfall (see Figure A.3).

For the four regions of concern the above discussion was used as a guide to determine the percolation component through an engineered disposal cell cover containing moisture barriers. The following percolation values were assumed: 38 mm for the northeast, 30 mm for the southeast, 25 mm for the midwest, and 1 mm for the southwestern locations. These values are used in the impacts analyses.

A.2.4 Surface Water Erosion

This section describes a model which may be used to predict the rate of loss of trench cover via sheet erosion for various regions and design parameters (material, length, slope, etc.). This model is based on the Universal Soils Loss Equation (USLE) developed by W. H. Wishmeier and his colleagues(26) and has been used extensively in the past 20 years to estimate sheet erosion for agricultural lands. Recent work has been performed to apply a modified form of this equation to the control of erosion during highway and other construction sites.(27) The equation is semi-empirical and may be used to estimate erosion of the trench covers or general erosion of the area surrounding the trenches. The equation, its parameters, and an example of its use follows. The USLE is usually stated as:

$$A = R \times K \times LS \times VM \qquad \text{(A-25)}$$

where:

A = The computed soil loss in tons/acre per year. This quantity may be converted to cubic meters using selected conversion factors.

R = The rainfall intensity factor, which is a measure of the erosion force of rainfall.

K = The soil erodibility factor, which is highly regional and varies from a low of 0.10-0.20 to a high of 0.37-0.49.

The next two parameters are of importance as they may be varied to control and minimize erosion:

LS = The topographic factor, which is a measure of the effect of lengths and steepness of slopes on the soil loss per unit area.

VM = The erosion control factor, which is a function of all erosion control measures such as vegetation, mechanical manipulation of the surface, chemical treatments, etc. For bare slopes VM=1.

For multiple slopes (as is the case here), the factor LS can be calculated using the following formula:

$$LS = \frac{1}{\lambda_e} \sum_{k=1}^{n} \frac{S_k}{(72.6)^{m_k}} \left\{ \left[\sum_{r=1}^{k} l_r \right]^{m_k+1} - \left[\sum_{r=1}^{k} l_r (1 - \delta_{1r}) \right]^{m_k+1} \right\} \cos^2\theta_k \qquad \text{(A-26)}$$

where:

$$\lambda_e = \sum_{r=1}^{n} l_r \qquad \text{(A-27)}$$

l_r = length of the $(r)^{th}$ segment

n = number of segments

δ_{1r} = Kronecker delta for segment (1).

θ_k = Angle between the $(k)^{th}$ segment and the horizon

$$S_k = (0.43+30 \sin\theta_k + 430 \sin^2\theta_k)/6.574 \qquad \text{(A-28)}$$

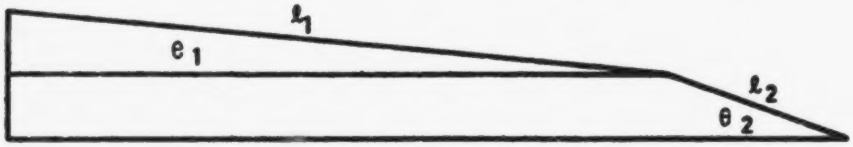
$$\begin{aligned} M_k &= 0.3 && \text{for} && \theta_k \leqslant 0.29° \\ &= 0.5 && \text{for} && 0.29° < \theta_k < 5.7° \\ &= 0.6 && \text{for} && 5.7° \leqslant \theta_k \end{aligned}$$

An illustrative example of the calculation and the use of the LS factor equation (A-26) is given below. This calculation is not related to the reference case (see below), but is provided to illustrate the concepts introduced. The example is based on Figure A.5.

This figure represents an idealized trench cover cross section. The maximum height is 10 m (32.8 ft). Two segments comprise the slope with lengths of 10 m (196.9 ft) and 20.6 m (65.6 ft) and horizontal angles of 1.72° and 14° respectively. Substituting these parameters in the equation leads to an LS factor of 4.19. Assuming an average erodability index of 0.28 and a rainfall intensity factor of 20 leads to a erosion potential of 82 tons/acre-yr.

It should be noted that this calculation is for bare slopes with the configuration as depicted in Figure A.5. This calculation would have to be repeated each time the configuration changed.

For long-term stability the last remaining factor VM in the USLE equation (A-25) must be considered. By a judicious choice of ground cover such as grass or rip rap, a reduction in the estimated soil loss per acre to less than one-percent of the value calculated can easily be attained. For example, assuming the VM is 1 percent, the erosion potential of the example case becomes 0.82 tons/acre-yr. Assuming a topsoil density of 100 lbs/ft^3 leads to a loss of 3.76×10^{-4} ft/yr


ℓ_1
θ_1
ℓ_2
θ_2

$\theta_1=1.72^\circ$ $\ell_1=60m$ (196.9FT.)

$\theta_2=14.0^\circ$ $\ell_2=20.6m$ (65.6FT.)

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OF THE MASS TRANSPORT PROBLEM -
SURFACE WATER EROSION SCENARIO

FIGURE A.5

or 1.15 x 10^{-2} cm/yr. Thus the type of final cover is quite critical in preventing sheet erosion.

Prediction of long-term erosion based on empirical and/or theoretical equations cannot help but be speculative. For example, the above case leads to a calculated complete erosion of one meter of disposal cell cover in about 8700 years. It is not sensible to rely on predictions that depend on numerous uncontrollable factors that far into the future. As stated previously in Section 3.6, for the erosion scenarios in this work, it will be assumed that the soil will be eroded at a rate of about one meter per 1000 years. The above equations and estimates, however, will be used to estimate the transfer factors.

Based on the above estimated soil loss of 0.82 tons/acre per year, the soil/waste mixture mobilization rate E (see Section 3.6) can be calculated to be 1.84x10^2 g/m^2-yr.

A.3 Other Transfer Factors

This section considers several other transfer factors outlined in Figure A.1, namely the air-to-air transfer factor, air-to-soil transfer factor, and water-to-soil transfer factor.

A.3.1 Air-to-Air Transfer Factor

This section considers the atmospheric dispersion equations which can be used to calculate the air-to-air transfer factor applicable to chronic release scenarios. This is utilized to calculate population exposures resulting from waste incineration and the exposed waste scenarios. To determine population exposures from waste incineration, generic population distributions for four U.S. regions have been assumed and are given in Appendix C. To account for potential future population growth, the population is assumed to be multiplied by 2 for the intruder-initiated exposed waste scenario, and by 3 for the erosion-initiated exposed waste scenario.

The assumption of a generic population distribution (population does not depend on the direction from the source point) is calculationally equivalent to the assumption that all wind directions are equally likely. For site specific data, this assumption would have to be modified. The transfer factor applicable to this source term, assuming ground-level release and sector-spread (22.5° sectors) dispersion, is:(28-29)

$$f_s = 2.032/(16\sigma_z\ ur) \qquad \text{(A-29)}$$

where:

σ_z = vertical standard deviation of the plume (m).
u = wind speed, in (m/sec).
r = distance from the release point, in (m).

The vertical standard deviation of the plume (σ_z) is given as a function of distance (r) and stability class in many references. One form for this factor is:(7)

$$\sigma_z = (ar)(1+br)^c \tag{A-30}$$

where r is the distance from the release point, and where a, b, and c are constants that depend on the stability class. Assuming that (see references 30 and 31) the wind is equally divided between Pasquill Stability classes C (wind speed 3 m/s), D (wind speed 3 m/s), and F (wind speed 2 m/s), the calculation yields.

$$f_s = 4.156E\text{-}8 \times (r^{-2}) \times q(r) \tag{A-31}$$

where:

$$q(r) = [0.133 \sqrt{1+.0002r} + 0.178 \sqrt{1+.0015r} + 1 +.0003r] \tag{A-32}$$

where (f_s) is in units of (yr/m^3) and (r) is in units of meters.

A.3.2 Air-to-Soil Transfer Factor

Radionuclide-bearing airborne particulates can deposit on the ground as a result of gravitational settling of the particles. This "fallout deposition" results in soil contamination and must be accounted for in human exposure pathways that involve contacting or use of soil (e.g., to grow food). The transfer factor to be used in obtaining soil radioactivity based on airborne particulate concentrations is derived in this section.

The air-to-soil fallout deposition transfer factor can be given as:

$$T_{as} = C_s/C_a \tag{A-33}$$

where:

T_{as} = the air-to-soil transfer factor (dimensionless)
C_s = the soil concentration, in (Ci/m^3)
C_a = the total air concentration, in (Ci/m^3)

The soil concentration will be dependent upon the deposition rate and can be given as:

$$D_s = C_{ap} V_p \tag{A-34}$$

where:

D_s = deposition rate, in $(Ci.m^{-2}.sec^{-1})$
C_{ap} = air concentration of particle size (p), in (Ci/m^3)
V_p = deposition velocity (m/sec) of particle size (p).

where C_a is defined as the sum of C_{ap} over all (p). The deposition velocity can be given for two ranges of particle sizes, such that 1 um to 10 um particles (5 um mean diameter) have a deposition rate of 0.010 m/sec, and 10 um to 80 um particles (35 um mean diameter) have a deposition rate of 0.0882 m/sec. Using a normalized direct air concentration of 1 Ci/m^3, (D_s) is therefore calculated to be 0.098 $Ci/(m^2\text{-}sec)$.

The soil concentration over a period of time can be calculated from the formula:(32)

$$C_s = (D_s/d)\ (1 - \exp[-(\lambda_e + \lambda)t])/(\lambda_e + \lambda) \tag{A-35}$$

where:

C_s = the soil concentrations, in (Ci/m^3)
D_s = the deposition rate, in $(Ci/m^2\text{-}sec)$
d = depth of mixing, in (m). This parameter is usually taken as the depth of the soil-root zone.
λ = the radioactive decay constant, in (1/sec)
λ_e = effective removal constant, in (1/sec)
t = the time interval of deposition, in (sec)

The effective environmental removal constant accounts for removal by downward migration in soil, removal by surface water runoff, and loss due to chemical binding. It is calculated from an assumed half-life in soil of 50 years.(32)

A.3.3 Water-to-Soil Transfer Factor

Irrigation of crops with contaminated water will result in increased radionuclide concentrations in the recipient soil. The radionuclides will then be available for plant uptake via soil-to-root transfer. The soil contamination resulting from irrigation must therefore be accounted for by a transfer factor for this mechanism. The applicable equation is:

$$T_{ws} = C_s/C_w \qquad \text{(A-36)}$$

where (C_s) and (C_w) are the soil and water concentrations, in (Ci/m^3). The soil concentration will be directly dependent upon the irrigation rate concentration (D) which is given by:

$$D = C_w\, I \qquad \text{(A-37)}$$

where:

D = the surface area contamination rate, in (Ci/m^2-day)
I = the irrigation rate, in ($m^3.m^{-2}.day^{-1}$)
C_w = the water concentration, in (Ci/m^3)

The subsequent soil concentration (C_s) dependent upon (D) over time (t), will be obtained by:(32)

$$C_s(t) = (D/d)\ (1 - \exp[-(\lambda_e + \lambda)t])/(\lambda_e + \lambda) \qquad \text{(A-38)}$$

where:

$C_s(t)$ = the soil concentration, in (Ci/m^3)
d = depth of mixing (see Section A.3.2)
λ = the physical decay constant, in (1/day)
λ_e = the effective removal constant, in (1/day)
t = the time over which irrigation occurs, in (day)

The effective removal constant may be calculated from an assumed half-life of 25 years (see Appendix B). This constant accounts for removal of contamination due to such processes as wind erosion, chemical binding and leaching, and other variables.

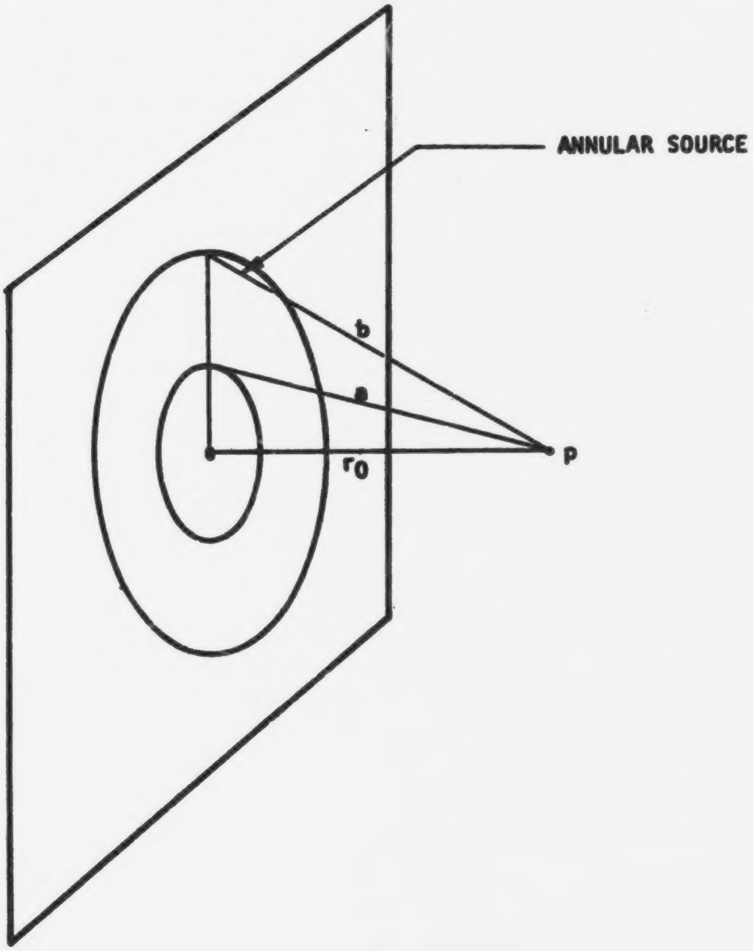
Variables such as irrigation rate, climatic conditions, and soil characteristics are only a few of the variables which need consideration. The irrigation rate may be dependent upon the crop, (e.g., wheat needs less irrigation than rice), the climatic conditions and the geographic location. For example, the Midwest wheat fields will need more irrigation during a hot, dry period than will western citrus groves during periods of optimal temperatures and rainfall. Also, variations in soil characteristics can influence the irrigation rate. A porous soil, for example, will retain more water than a nonporous one, thus reducing the frequency of irrigation. These individual characteristics are accounted for in the effective removal constant (λ_e). The irrigation rate will, however, be the deciding factor in the calculation of soil concentration.

A.4 Direct Radiation Exposures

Intruders inhabiting a site may receive chronic radiation doses as a result of direct exposures to alpha, beta, and gamma rays emitted by the waste (the term "gamma rays" as used here means gamma rays, x-rays, and bremsstrahlung). The most important of these radiations is gamma rays since alpha and beta rays have extremely short ranges. External exposure to alpha rays is not considered in this appendix. Beta rays are considered, however, in determining exposures resulting from human immersion in air containing suspended radioactivity, and exposures resulting from standing on surface contaminated ground (see Appendix B). Only gamma rays are considered in this section and for determining exposures resulting from standing on soil that is homogeneously contaminated. The exposures experienced depend on factors such as source strength, gamma ray energies, self-shielding effects of the waste form and packaging, thickness of covering over the waste, and geometry of the exposure.

The intruder scenarios postulated in Sections 2.0 and 3.0 of the report involves a person living on top of the waste disposal site. The actual geometry of the situation may be complicated but as a first-order approximation is considered to be represented by a homogeneous mixture of waste and soil extending horizontally and downward to infinity (i.e., an infinite slab source). The exposure can then be calculated based on this geometry, or estimated empirically by measurements taken over a simulated source.

The method used here to estimate exposure rates is empirical. The exposure rate measurements were made above soil uniformly contaminated with a variety of radionuclides.(33) The exposure rate per unit of source activity was plotted versus gamma energy (see Figure A.6) and the graph was used to directly obtain the exposure rate for a given radionuclide based on the average energy of its gamma emissions. Build-up of the exposure rate within the source is intrinsically


ANNULAR SOURCE
b
a
p
r0

GEOMETRY OF EXPOSURE

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FIGURE A.6

accounted for with this method (buildup is defined as the actual exposure from the total gamma flux divided by the exposure due only to uncollided photons).

The calculational method of obtaining the exposure rate, while not used in the report, is presented here to illustrate considerations important to determining exposure rates. The method is described by Lamarsh(34) and is given as:

$$X = C\,\phi_b \tag{A-39}$$

where:

X = gamma ray exposure rate in air, in (mR/h)

C = conversion factor

ϕ_b = buildup flux, equal to that flux of monoenergetic gamma rays of energy (E_o) which gives the same exposure rate at a point as does the actual distributed-energy gamma ray flux at that point.

The factor (C) converts the buildup flux to exposure rate. It is given by the following equation.

$$C = 0.0659\,E_o\,(\mu_o/\rho)^{air} \tag{A-40}$$

where:

E_o = initial photon energy, in MeV

$(\mu_o/\rho)^{air}$ = mass absorption coefficient for air for photons of energy E_o, in cm^2/g.

The buildup flux may be represented by the equation:(33)

$$\phi_b = B\,\phi_u \tag{A-41}$$

where:

B = exposure buildup factor

ϕ_u = photon flux at the point of interest due only to source photons that have not interacted in the medium -- i.e., the uncollided flux, in photons per cm^2/sec.

Determination of the uncollided flux and buildup factor are strongly dependent on the geometry of the source. Postulation of a homogeneous infinite slab source yields the following equations for these parameters:(33,34)

$$\phi_u = S_v/2\mu \qquad \text{(A-42)}$$

$$B = \sum_n A_n/(1+\alpha_n) \qquad \text{(A-43)}$$

where:

S_v = source strength, in Ci/m^3

μ = linear attenuation coefficient of the source, in (cm^{-1}).

A_n, α_n = energy dependent coefficients used in evaluating the Taylor form of the build-up factor.

After evaluating the build-up factor, it is multiplied by (C) to obtain the exposure rate.

Experimentally determined exposure rates assume that an inadvertant intruder is standing on the bare soil/waste mixture. A worst case scenario would be an intruder occupying a below-ground-level structure. The intruder would thus be exposed from all sides except the roof. A completely enclosed reclaimer would be exposed to an infinite source, thus:

$$\phi_u = S_v/\mu \qquad \text{(A-44)}$$

This is twice the flux calculated for the infinite slab geometry (equation A-42). The factor of two difference is not considered significant relative to the potential variations in surface flux expected at an actual site. In any case, any below-ground-level structure would require a floor and supporting walls, which would most likely be made of a material such as concrete. The concrete would provide considerable shielding. For example, a one foot thick concrete slab results in a reduction factor of 0.03 for the predominant gamma-ray of Cs-137 having an energy of 0.66 MeV.(35)

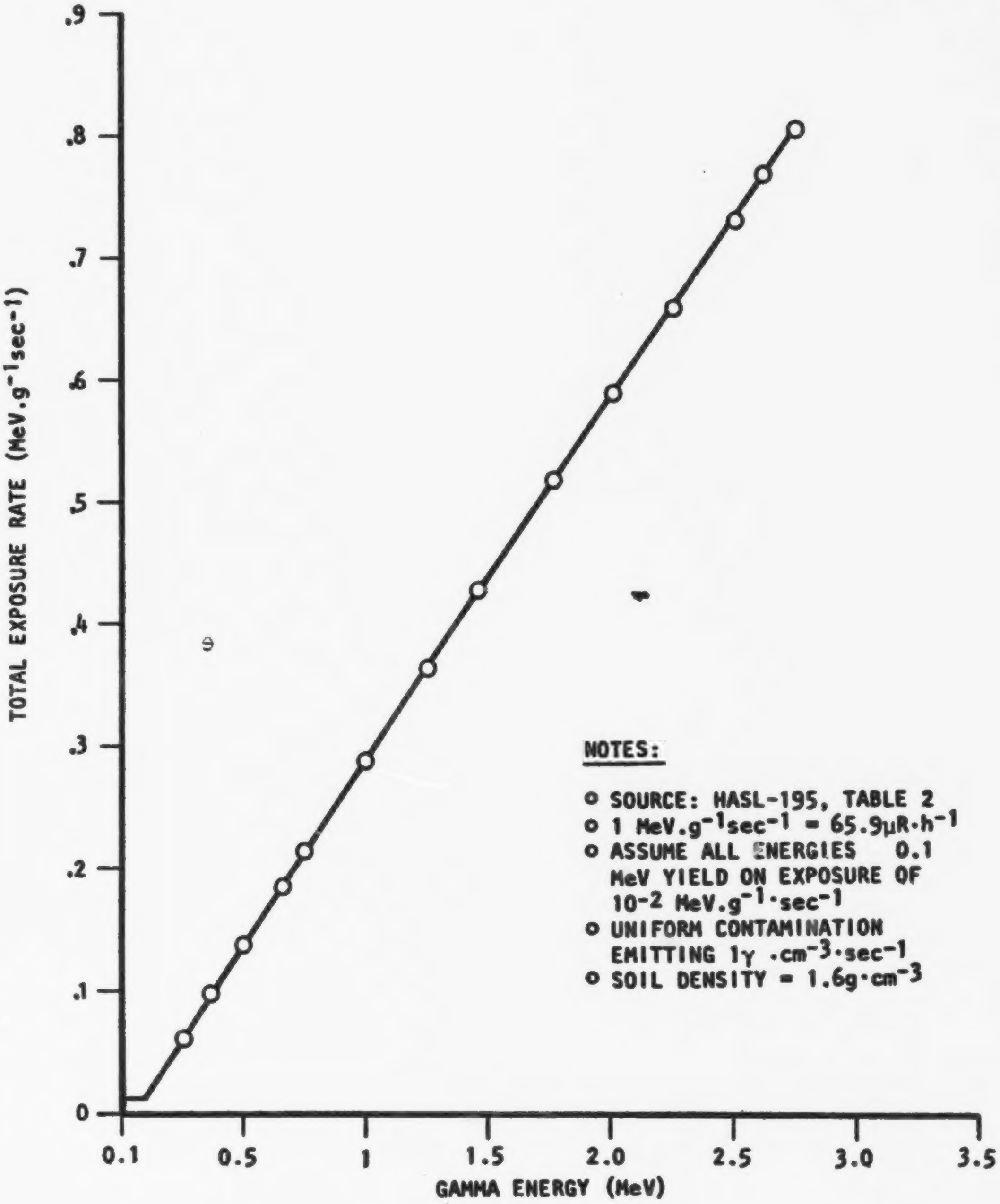
The actual exposure that an intruder would experience would be much less than the worst case values since waste form and packaging and other factors would act to reduce the exposure. Moreover, the geometry of the exposure is not a fully infinite slab, and the reduction in the radiation is considerable. This case may be approximated by utilizing equations presented in reference 33 for the derivation of the uncollided flux from a disk source. The geometry of exposure is shown in Figure A.7.

In this case the uncollided flux is calculated to be:(33)

$$\phi_u = \frac{S}{2\mu} [\ E_1(\mu a) - E_1(\mu b)\ ] \tag{A-45}$$

where a and b are the distances from the exposure point to the radii shown above, and $E_1(x)$ is the first order exponential integral. Assuming that the ratios of the collided fluxes for two different geometries may be approximated by the ratio of the uncollided fluxes for the two geometries, this equation may be manipulated to yield correction factors for finite disk sources or for finite annular sources.

One subcase of the direct exposure case would involve calculating the exposures resulting from utilization of the closed disposal facility as a public recreation area -- e.g., a golf course. For this case,



TOTAL EXPOSURE RATE VS. GAMMA ENERGY
AT ONE METER ABOVE BULK CONTAMINATED SOIL

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FIGURE A.7

the potential exposures would be considerably reduced (e.g., orders of magnitude) due to the shielding afforded by the thickness of the cover. The correction factor that will be applied in this case is:

$$f_c = B \exp[-(\mu/\rho) \times \rho \times t] \tag{A-46}$$

where:

B = buildup factor

μ/ρ = mass attenuation coefficient, in cm^2/g

ρ = density of the cover, in g/cm^3

t = cover thickness, in cm

The cover material may be assumed to be soil, hence the mass attenuation coefficient used in the above calculation can be approximated by that for SiO_2.(35) The assumed density is 1.6 g/cm^3. The product of (μ/ρ) and (ρ) is the linear attenuation coefficient (μ), which is an energy-dependent parameter, and hence is different for each radionuclide.

Table A-6 presents an "effective" gamma energy for each nuclide, which is the highest energy gamma emitted by the nuclide in reasonable abundance. The relative abundances of the "effective" gammas (percent of gammas emitted that are of the "effective" energy) and the average gamma energies are presented in Table A-6 for comparison. It should be noted that the "effective" energy is not necessarily the maximum energy gamma emitted by the nuclide. Maximum-energy gammas for some nuclides are emitted in such small abundances that it would be inappropriate to determine cover thicknesses based on those energies. The values for (μ) based on the "effective" energies for SiO_2 at 1.6 g/cm^3, are presented in Table A-6.

The buildup factors used in equation A-43 are for a plane, monodirectional source, which is assumed to be representative of the "infinite-

TABLE A-6 : Gamma Dose Reduction Factors For Varying Soil Cover Thicknesses

Nuclide[a]	Average Energy	Effective[b]		μ[c]		Soil Thickness (meters) vs. Dose Reduction Factor (f)[d]						
		Energy	Abundance		R.L.:	1	4.3	7.3	10.1	12.8	15.4	2.6
	(MeV)	(MeV)	(%)	(1/cm)	f :	0.368	E-1	E-2	E-3	E-4	E-5	ΔE-1
Co-60	1.25	1.33	50	0.086		0.12	0.50	0.85	1.17	1.48	1.79	0.30
Ni-59	0.35	0.35	100	0.16		0.06	0.27	0.45	0.63	0.79	0.95	0.16
Sr-90	0.76	0.76	100	0.12		0.09	0.37	0.64	0.88	1.11	1.34	0.23
Nb-94	0.787	0.871	50	0.11		0.09	0.39	0.67	0.93	1.18	1.42	0.24
I-129	0.040	0.040	100	0.11		0.01	0.03	0.05	0.07	0.09	0.11	0.02
Cs-137	0.662	0.662	100	0.12		0.08	0.34	0.58	0.81	1.02	1.23	0.21
U-235	0.180	0.204	7	0.21		0.05	0.21	0.35	0.48	0.61	0.74	0.12
U-238	0.51	0.90	60	0.11		0.09	0.40	0.68	0.94	1.19	1.43	0.24
Np-237	0.211	0.31	60	0.18		0.06	0.25	0.42	0.58	0.73	0.88	0.15
Pu-238	0.108	0.150	11	0.22		0.04	0.19	0.33	0.45	0.58	0.69	0.12
Pu-239	0.221	0.414	16	0.15		0.07	0.28	0.48	0.67	0.84	1.02	0.17
Pu-241	0.145	0.145	100	0.22		0.04	0.19	0.33	0.45	0.58	0.69	0.12
Am-241	0.060	0.060	100	0.42		0.02	0.10	0.18	0.24	0.31	0.37	0.06
Am-243	0.073	0.075	93	0.32		0.03	0.13	0.23	0.31	0.40	0.48	0.08
Cm-243	0.249	0.278	47	0.18		0.06	0.25	0.42	0.58	0.73	0.88	0.15
Cm-244	0.062	0.150	6	0.22		0.04	0.19	0.33	0.48	0.58	0.69	0.12

(a) The following nuclides have been excluded from this table due to low effective gamma energies: H-3, C-14, Fe-55, Ni-63, Tc-99, Cs-135, and Pu-242.

(b) Effective gamma abundance is the percent of gammas emitted that are of the effective energy.

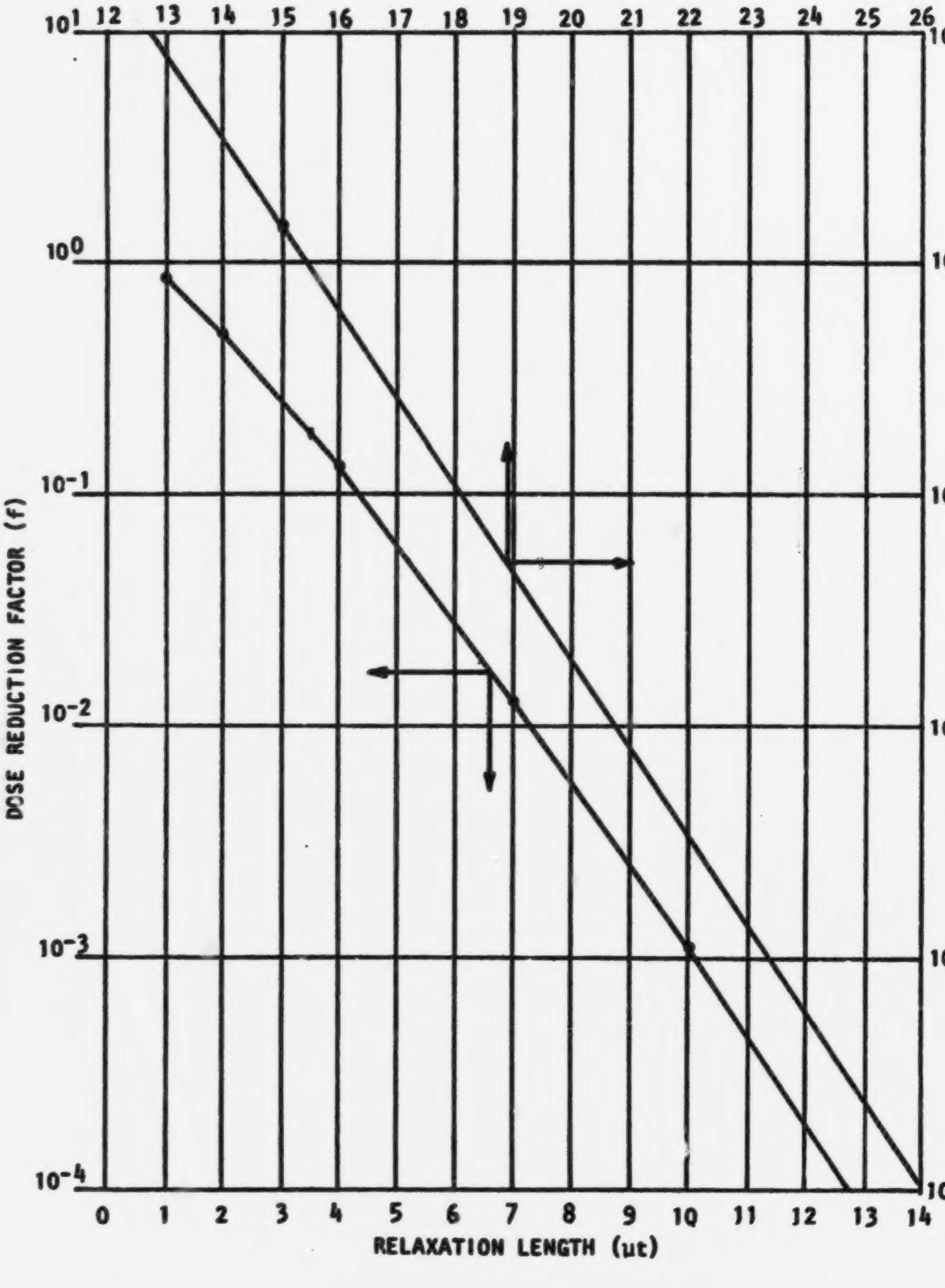
(c) Linear Attenuation coefficient (μ) for SiO_2 at a density of 1.6 g/cm^3.

(d) R.L. = Relaxation lengths, f = ratio of the attenuated to unattenuated dose.

slab" waste geometry. Values for (B) are dependent upon the gamma ray energy, type of cover material, and cover thickness. Since (B) values for SiO_2 were not readily available, the values used here are an average of those for water and iron.(35) In addition, a gamma energy of 0.5 MeV is assumed for all gammas, since all but one of the gammas of concern are less than 1 MeV and (B) values were available only for energies of 0.5, 1.0, 2.0 and higher MeV gammas. This is a somewhat conservative assumption since (B) values increase at lower energies. However, the values at 0.5 and 1.0 MeV do not differ greatly, especially for relatively thin cover thicknesses. At a thickness equal to 15 relaxation lengths (i.e., flux attenuates to e^{-15}, or approximately $3x10^{-7}$, of the original flux) the value for (B) is only a factor of 2 higher at 0.5 MeV than at 1.0 MeV. Therefore, multiple-energy buildup factors are not used in these calculations since they would complicate the calculations for relatively little increase in accuracy.

The thickness of soil (SiO_2) required to reduce the dose from uncovered waste by successive orders of magnitude are also presented in Table A-6 for each nuclide. The corresponding number of relaxation lengths (ut) is also indicated since the reduction factors were obtained from a plot of (f_c) vs. (ut), as presented in Figure A.8.

Table A-6 may be used to calculate the thickness of soil required to reduce the intensity of a given radionuclide radiation by a given order of magnitude. For example, for Cs-137, an average thickness of 0.81 m of soil is required to result in reduction in gamma radiation intensity of 10^{-3}, and a thickness of 1.02 m of soil results in a reduction of 10^{-4}. Using this table, and averaging over the radionuclides expected to be present in LLW, a generic reduction factor of 1200 may be calculated for 1 meter thick soil shielding.



EXTERNAL GAMMA DOSE REDUCTION VS. SOIL THICKNESS

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FIGURE A.8

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APPENDIX B

PATHWAY DOSE CONVERSION FACTORS

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APPENDIX B : Pathway Dose Conversion Factors

The purpose of this appendix is to present the data and calculational procedures utilized to determine the total pathway dose conversion factors (PDCF's) presented and discussed in Section 2.3 of the main report. An introduction and background to the appendix is presented in Section B.1, and the fundamental dose conversion factors utilized in the calculation of the PDCF's are discussed in Section B.2. After these two background sections, the calculational procedures and uptake parameters utilized are presented in Section B.3. The computer code utilized in the calculations is given in Section B.4.

B.1 Introduction and Background

The human exposure pathways considered in this report, resulting from the disposal of low level radioactive waste (LLW), are presented in Figure 2.5 for each of the seven postulated exposure scenarios.

Although each pathway component (e.g., foliar deposition-cow-milk-human ingestion) is calculated by a unique equation (or set of equations), many of the combined pathways presented in Figure 2.5 represent combinations of pathway components. For example, the food (soil) pathway is a combination of all pathway components initiated by root uptake of radionuclide contamination. These components include the direct plant-human ingestion component, and the plant-cattle-beef-human ingestion and plant-cow-milk-human ingestion components. A description of the components of the nine combined pathways is given in Table 2-2.

The grouping of pathway components into the combined pathways given in Figure 2.5 facilitates the development and use of the computer code employed to calculate the total PDCF's, as given in Section B.4. Each major branch of the diagram has been assigned a PDCF for which the formulae are discussed later in this appendix.

All the PDCF's are calculated from fundamental dose conversion factors (DCF's) obtained from the existing literature. Conventionally, DCF's are the more common factors utilized in the computation of human exposures. For a generic study, however, in the absense of site specific information, generic information on the translocation parameters (uptake factors) have been assumed and utilized in the calculation of the PDCF's. For evaluation of a specific site, the fundamental DCF's could be utilized in conjunction with site specific uptake factors.

B.2 Fundamental Dose Conversion Factors

All the PDCF's are calculated based on five fundamental dose conversion factors: inhalation 50-year committed dose in units of mrem per pCi inhaled; ingestion 50-year committed dose in units of mrem per pCi ingested; and three different direct radiation exposure factors. The use of these last three factors depends on the particular biota access location considered, and include factors for volume contamination of soil (mrem/year per pCi/m^3), surface contamination of soil (mrem/year per pCi/m^2), and air contamination (mrem/year per pCi/m^3). The values of these fundamental DCF's are a function of the radionuclide of concern and the organ receiving the dose. A brief description of the fundamental DCF's is provided below.

B.2.1 Ingestion DCF

For the fundamental ingestion dose conversion factors (which are denoted by DCF1), existing models that are presented in several documents are considered to be reasonable representations of the human organism.(1-3) In this report, the fundamental ingestion DCF's given in reference 2, which are reproduced in Table B-1, have been utilized. A brief discussion of the internal factors obtained from reference 2 is presented below.

TABLE B-1 . Ingestion Fundamental Dose Conversion Factors
(mrem per pCi ingested)

	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	1.05E-7	0.	1.05E-7	1.05E-7	1.05E-7	1.05E-7	1.05E-7
Be-10	7.94E-8	3.18E-6	4.91E-7	0.	3.71E-7	0.	2.68E-5
C-14	5.68E-7	2.84E-6	5.68E-7	5.68E-7	5.68E-7	5.68E-7	5.68E-7
Cl-36	0.	0.	0.	0.	0.	0.	0.
Ca-41	2.00E-5	1.83E-5	0.	0.	0.	0.	1.84E-7
Fe-55	4.43E-7	2.75E-6	1.90E-6	0.	0.	1.06E-6	1.09E-6
Co-60	4.72E-6	0.	2.14E-6	0.	0.	0.	4.02E-5
Ni-59	1.63E-6	9.76E-6	3.35E-6	0.	0.	0.	6.90E-7
Ni-63	4.36E-6	1.30E-4	9.01E-6	0.	0.	0.	1.88E-6
Sr-90	1.86E-3	7.58E-3	0.	0.	0.	0.	2.19E-4
Nb-94	1.86E-9	6.22E-9	3.46E-9	0.	3.42E-9	0.	2.10E-5
Mo-93	2.03E-7	0.	7.51E-6	0.	2.13E-6	0.	1.22E-6
Tc-99	5.02E-8	1.25E-7	1.86E-7	0.	2.34E-6	1.58E-8	6.08E-6
I-129	9.21E-6	3.27E-6	2.81E-6	7.23E-3	6.04E-6	0.	4.44E-7
Cs-135	7.99E-6	1.95E-5	1.80E-5	0.	6.81E-6	2.04E-6	4.21E-7
Cs-137	7.14E-5	7.97E-5	1.09E-4	0.	3.70E-5	1.23E-5	2.11E-6
Eu-152	3.90E-8	1.95E-7	4.44E-8	0.	2.75E-7	0.	2.56E-5
Eu-154	5.38E-8	6.15E-7	7.56E-8	0.	3.62E-7	0.	5.48E-5
Re-187	0.	0.	0.	0.	0.	0.	0.
Pb-210	5.44E-4	1.53E-2	4.37E-3	0.	1.23E-2	0.	5.42E-5
Bi-207	0.	0.	0.	0.	0.	0.	0.
Ra-226	4.60E-3	4.60E-2	5.74E-6	0.	1.63E-4	0.	3.32E-4
Th-230	5.70E-5	2.06E-3	1.17E-4	0.	5.65E-4	0.	6.02E-5
Th-232	1.50E-4	2.30E-3	1.00E-4	0.	4.82E-4	0.	5.12E-5
U-233	5.28E-5	8.71E-4	0.	0.	2.03E-4	0.	6.27E-5
U-234	5.17E-5	8.36E-4	0.	0.	1.99E-4	0.	6.14E-5
U-235	4.86E-5	8.01E-4	0.	0.	1.87E-4	0.	7.81E-5
U-236	4.96E-5	8.01E-4	0.	0.	1.91E-4	0.	5.76E-5
U-238	4.54E-5	7.67E-4	0.	0.	1.75E-4	0.	5.50E-5
Np-237	5.54E-5	1.37E-3	1.19E-4	0.	4.12E-4	0.	7.94E-5
Pu-238	1.71E-5	6.80E-4	9.58E-5	0.	7.32E-5	0.	7.30E-5
Pu-239	1.91E-5	7.87E-4	1.06E-4	0.	8.11E-5	0.	6.66E-5
Pu-241	3.32E-7	1.65E-5	8.44E-7	0.	1.53E-6	0.	1.40E-6
Pu-242	1.84E-5	7.29E-4	1.02E-4	0.	7.81E-5	0.	6.53E-5
Am-241	5.41E-5	8.19E-4	2.88E-4	0.	4.07E-4	0.	7.42E-5
Am-243	5.30E-5	8.18E-4	2.78E-4	0.	3.99E-4	0.	8.70E-5
Cm-243	3.75E-5	6.39E-4	2.41E-4	0.	1.75E-4	0.	7.81E-5
Cm-244	2.87E-5	4.83E-4	2.07E-4	0.	1.34E-4	0.	7.55E-5

> "Equations for calculating internal dose committment factors were derived from those given by the ICRP(1) for body burden and maximum permissible concentration (MPC). Effective absorbed energies for the radionuclides were calculated from the ICRP model. When necessary, these energies were corrected for the ingrowth of daughter radionuclides following ingestion or inhalation of the parent. . . . Quality factors, as listed in ICRP Publication 2,(1) were applied to the effective energies, including the value of 1.7 for beta particles and electrons with energies equal to or less than 30 keV. Age dependent parameters were applied when available, but, where data were lacking, metabolic parameters for the Standard Man(1) were used for other age groups."

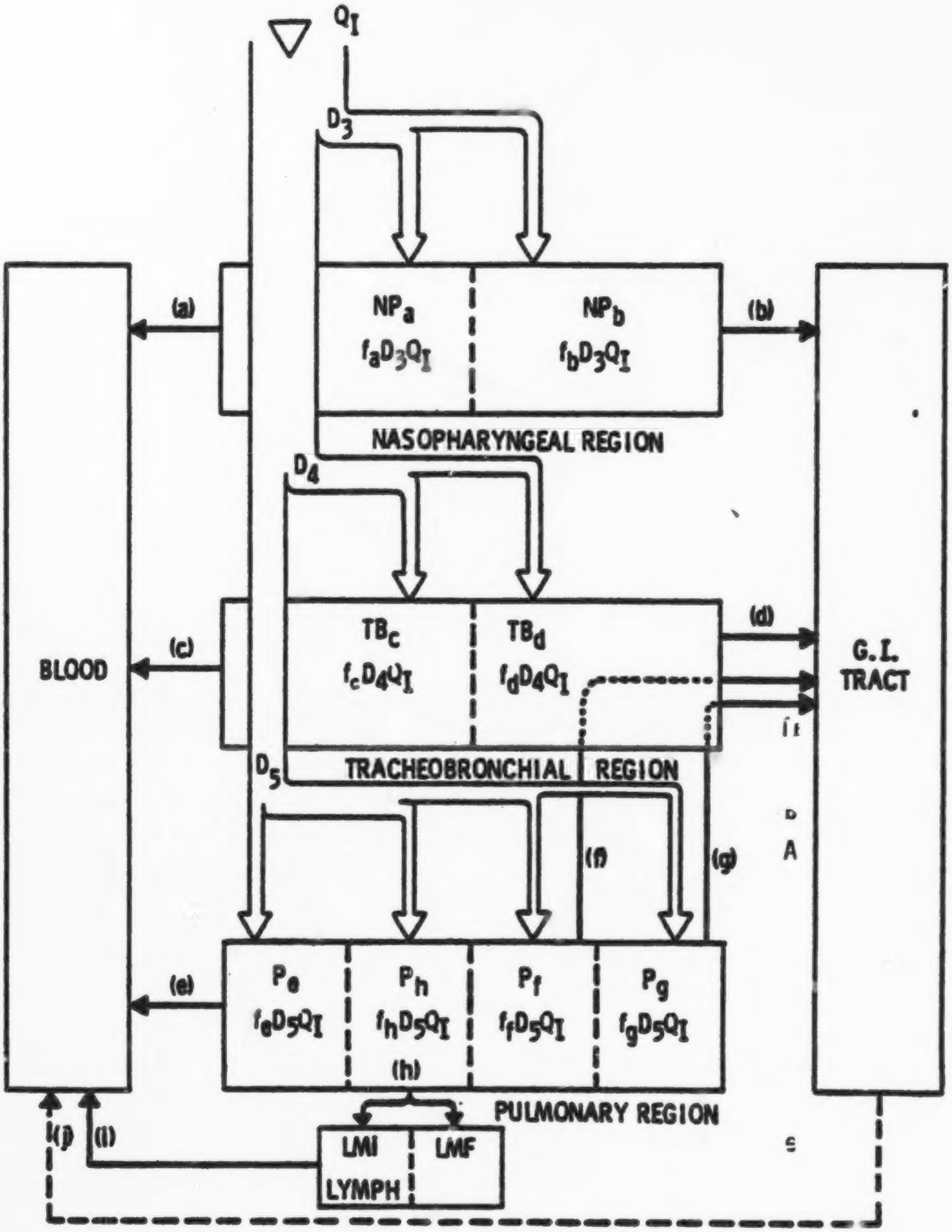
B.2.2 Inhalation DCF's

The most comprehensive compilation of information on the initial deposition of inhaled particles in the respiratory tract was published by the ICRP Task Group on Lung Dynamics in 1966.(4) This report includes an anatomical description of the respiratory tract, characteristics of particle size distribution, and physiological parameters describing the inhalation process. Based on these parameters, a quantitative model for initial respiratory tract deposition is developed. The report also describes a lung clearance model that is more comprehensive than those used previously; it is based on extensive studies with laboratory animals and results of human contamination cases and it also incorporates the major clearance processes. With the lungs compartmentalized (nasopharyngeal region, tracheobroncial region, and pulmonary region), and considering lymph nodes, blood and the gastrointestinal tract, the Task Group calculates rate constants for transfer of particles between compartments. With this model, various retention characteristics may be described for compounds of all the elements in the periodic table.

The complete lung model, as proposed by the Task Group(4,5) has been utilized in this report for the calculation of the fundamental inhalation dose conversion factors. This model permits a more realistic calculation of radiation dose to the human respiratory tract from inhaled radioactivity than does the initial ICRP lung model.(2) In this model, the respiratory tract is divided into three regions: the nasopharyngeal (NP), the tracheobronchial (TB), and the pulmonary (P). The schematic representation of the respiratory tract used in the development of the mathematical model for the deposition and clearance of inhalated radionuclides is shown in Figure B.1.

Deposition is assumed to vary with the aerodynamic properties of the aerosol distribution and is described by the three parameters D_3, D_4, and D_5. These parameters represent the fraction of the inhaled material, Q_I, initially deposited in the NP, TB, and P regions, respectively. Each of the three regions of deposition are further subdivided into two or more subcompartments. Each subcompartment represents the fraction of material initially in a compartment that is subject to a particular clearance process. This fraction is represented by f_k, where k indicates the clearance pathway. The quantity of material in the TB region, for example, cleared by process (c) is then represented by the product $f_c D_4 Q_I$. Values of (f_k) and of the clearance half-times (T_k) for each clearance process for the three solubility classes of aerosols used in the model are those suggested by the ICRP (Appendix A, Table A-5 of reference 4). Values of the deposition fractions (D_3, D_4, and D_5) as functions of the median aerodynamic diameters (MAD) of the inhaled particles have been published in the form of a graph.(1) Routines to generate these values directly from the AMAD have been included in the model and yield essentially the same values as those presented by the Task Group for the range of particle size distributions considered by the group.

The respiratory tract model has been incorporated by Voilleque into a simple metabolic model for acute inhalation exposures and the model


Q_I
D_3
NP_a
f_aD_3Q_I
NP_b
f_bD_3Q_I
(a)
(b)
NASOPHARYNGEAL REGION
D_4
TB_c
f_cD_4Q_I
TB_d
f_dD_4Q_I
(c)
(d)
BLOOD
G.I. TRACT
TRACHEOBRONCHIAL REGION
D_5
(f)
(g)
P_e
f_eD_5Q_I
P_h
f_hD_5Q_I
P_f
f_fD_5Q_I
P_g
f_gD_5Q_I
(e)
(h)
PULMONARY REGION
(j)
(i)
LMI
LMF
LYMPH

SCHEMATIC DIAGRAM OF THE TASK GROUP LUNG MODEL

DAMES & MOORE

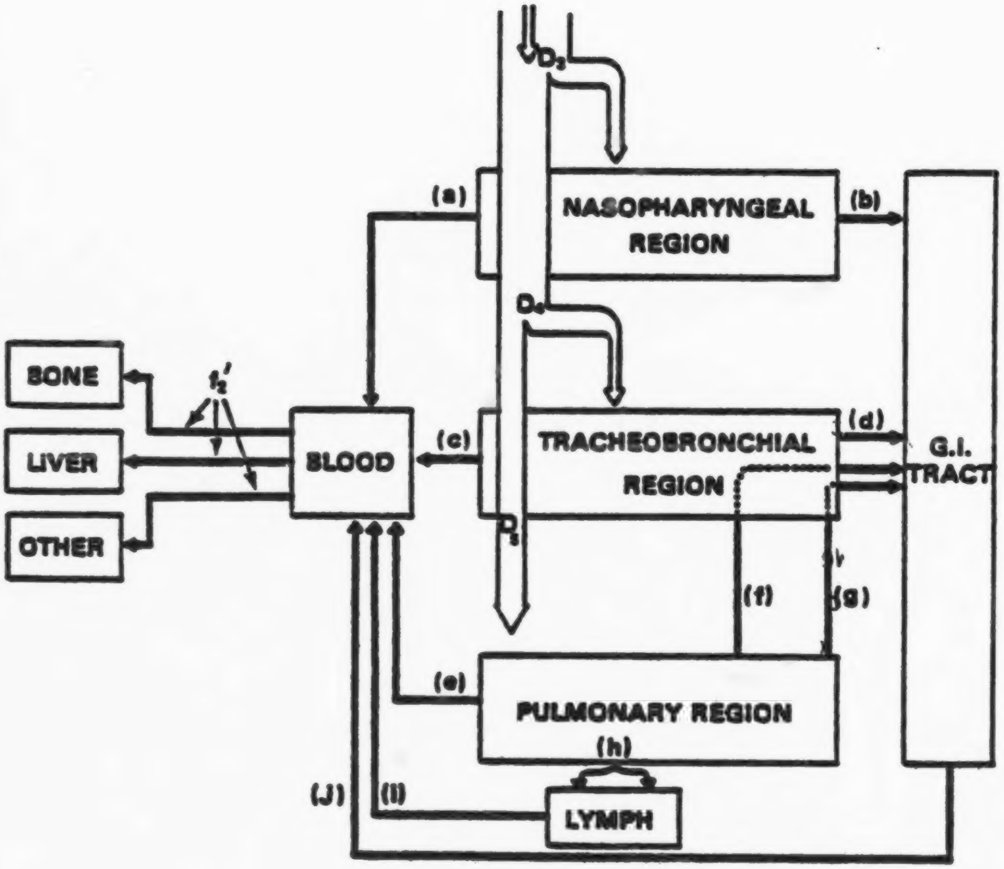
Figure B.1

was programmed into a computer code called AERIN.(8) In this model, transport of a radionuclide from the respiratory tract lymphatic system and GI tract to other organs and tissues where significant accumulations of the inhaled radionuclides occur, is assumed to take place via the blood. This translocation from the respiratory tract and lymphatic system to the blood has been described in some detail by the Task Group. Of the material clearing from the respiratory tract through the GI tract, a constant fraction, f_1, is assumed to be taken up by the blood. That moving to the n^{th} organ or tissue is assumed to be a constant fraction, f_{2n}, of the amount entering the blood stream at any time t. Once in the n^{th} organ, the activity is assumed to clear the organ (and the body) at a constant rate. Voilleque's program, AERIN(8), calculates the quantity of radionuclides present in and the dose received by organs of interest as a function of time following acute exposures.

The inhalation dose conversion factors utilized in this report have been obtained by utilizing a computer code called DACRIN(6) which incorporates the Task Group lung model as described by the program AERIN. A brief description of this code is presented below.

The DACRIN program calculates the effective radiation dose to any of 18 organs and tissues from inhalation of any one or combination of radionuclides considered by the ICRP. A maximum of 10 organs may be selected for any one case (run). In addition, up to five multiple intake intervals and 10 time intervals measured from the last intake may be selected for each case.

Input to the code, in its simplest form, consists of a few program control variables, the duration of inhalation exposure, ventilation rate, the time interval within which the dose is delivered, the organs of interest, the quantity of the radionuclide inhaled, its solubility class and its particle size. Input to the code in its most complex form, results from invoking an atmospheric dispersion model. It is


D$_3$
(a)
NASOPHARYNGEAL REGION
(b)
D$_4$
BONE
f_2'
LIVER
OTHER
BLOOD
(c)
TRACHEOBRONCHIAL REGION
(d)
G.I. TRACT
D$_5$
(f)
(g)
(e)
PULMONARY REGION
(h)
(J)
(I)
LYMPH

SCHEMATIC DIAGRAM OF DACRIN METABOLIC MODEL

Figure B.2

then necessary to input additional parameters which are determined by the particular atmospheric dispersion model selected for analysis.

Output of the code consists of the effective radiation dose to the selected organs at selected time intervals, for each radionuclide inhaled as indicated by the input.

The present DACRIN code extends previous codes based on the Task Group Lung Model to include calculating organ doses resulting from chronic inhalation exposure. A schematic presentation of the DACRIN metabolic model is shown in Figure B.2. A model for the dose to the GI tract from radionuclides moving through it is not included in the present version of the code, although some provisions have been made in the code for the eventual addition of a GI tract dose model.

The contribution to the pulmonary lung dose from the ingrowth of daughter radionuclides is computed indirectly by utilizing weighted values of the effective energy emitted by the daughter nuclides in the chain. Weighted values are calculated for each of the decay chains tabulated by the ICRP (1,7) for residence half times of 1 day, 50 days and 500 days (corresponding to solubility class D, W, and Y, respectively). These values are included in the organ data library.

The radionuclides considered, the solubility classes assumed in this report, and the calculated inhalation dose conversion factors, denoted by DCF2, are presented in Table B-2. The solubility classes assumed were based upon information presented in references 9 through 14.

B.2.3 Direct Radiation (Volume) DCF's

Exposure rate data for K-40, natural uranium, and thorium plus daughters uniformly distributed in soil as an infinitely thick slab source is presented in HASL-195.(15) Table 2 in reference 9, which presents exposure data as a function of gamma energy and height above soil

TABLE B-2 . Inhalation Fundamental Dose Conversion Factors (mrem per pCi inhaled)

	Solubility Class	Total Body	Bone	Liver	Thyroid	Kidney	Lung	GI-LLI
H-3	D	1.5E-7	0.	1.5E-7	1.5E-7	1.5E-7	1.5E-7	0.
Be-10	W	4.6E-8	1.9E-4	2.9E-5	0.	2.2E-5	1.1E-4	1.3E-5
C-14	D	3.4E-7	1.7E-6	3.4E-7	3.4E-7	3.4E-7	3.4E-7	2.6E-7
Cl-36	W	4.8E-6	0.	0.	0.	0.	1.4E-4	8.1E-7
Ca-41	W	1.4E-5	1.3E-4	0.	0.	0.	1.9E-6	9.0E-8
Fe-55	Y	2.4E-7	3.4E-7	1.0E-6	0.	0.	2.4E-5	3.9E-7
Co-60	Y	2.8E-6	0.	2.2E-6	0.	0.	3.0E-3	2.1E-5
Ni-59	W	1.4E-6	8.5E-6	3.1E-6	0.	0.	4.0E-6	3.4E-7
Ni-63	W	3.8E-6	1.2E-4	8.2E-6	0.	0.	1.1E-5	9.1E-7
Sr-90	D	3.0E-3	1.2E-2	0.	0.	0.	3.9E-6	2.8E-6
Nb-94	Y	8.2E-8	2.3E-7	1.6E-7	0.	1.5E-7	9.0E-5	9.3E-6
Mo-93	Y	1.2E-7	0.	4.6E-6	0.	1.4E-6	2.5E-4	0.
Tc-99	D	5.2E-8	2.6E-8	1.9E-7	0.	2.4E-6	8.3E-7	8.9E-7
I-129	D	7.8E-6	6.0E-16	1.0E-14	6.3E-3	8.7E-15	7.1E-7	6.9E-8
Cs-135	D	2.9E-6	1.2E-5	1.1E-5	0.	4.1E-6	1.8E-6	6.2E-8
Cs-137	D	2.6E-5	4.9E-5	6.7E-5	0.	2.3E-5	1.1E-5	3.2E-7
Eu-152	Y	1.5E-5	7.2E-5	1.7E-5	0.	7.7E-5	1.5E-3	4.5E-5
Eu-154	Y	9.5E-7	8.5E-6	1.9E-6	0.	4.9E-6	2.8E-4	4.9E-6
Re-187	D	4.7E-8	1.2E-8	3.9E-8	4.9E-7	0.	1.0E-7	1.1E-7
Pb-210	W	1.0E-5	3.2E-2	8.2E-3	0.	2.6E-2	1.3E-2	1.1E-6
Bi-207	W	6.3E-7	1.2E-7	5.2E-6	0.	1.7E-5	2.3E-4	1.5E-5
Ra-226	W	1.9E-1	2.7E-1	0.	0.	0.	1.0E-1	2.1E-5
Th-230	W	6.7E-2	2.2E-0	1.4E-1	0.	6.6E-1	4.4E-2	2.9E-5
Th-232	Y	3.2E-2	9.3E-1	4.4E-2	0.	2.1E-1	5.9E-1	2.8E-5
U-233	Y	2.5E-4	4.1E-3	0.	0.	9.6E-4	4.6E-1	3.5E-5
U-234	Y	2.4E-4	3.9E-3	0.	0.	9.4E-4	4.5E-1	3.4E-5
U-235	Y	2.3E-4	3.8E-3	0.	0.	8.8E-4	4.2E-1	3.7E-5
U-236	Y	2.3E-4	3.8E-3	0.	0.	9.1E-4	4.3E-1	3.2E-5
U-238	Y	2.1E-4	3.6E-3	0.	0.	8.2E-4	3.9E-1	3.0E-5
Np-237	W	6.5E-2	1.5E-0	1.4E-1	0.	4.8E-1	4.5E-2	3.0E-5
Pu-238	Y	2.5E-2	5.1E-1	3.5E-1	0.	1.1E-1	5.1E-1	3.9E-5
Pu-239	Y	2.8E-2	6.0E-1	3.9E-1	0.	1.2E-1	4.8E-1	3.7E-5
Pu-241	Y	3.8E-4	9.3E-3	5.7E-3	0.	1.8E-3	8.5E-4	6.9E-7
Pu-242	Y	2.7E-2	5.6E-1	3.8E-1	0.	1.2E-1	4.6E-1	3.5E-5
Am-241	W	6.3E-2	8.9E-1	8.3E-1	0.	4.8E-1	5.3E-2	3.5E-5
Am-243	W	6.2E-2	8.8E-1	8.1E-1	0.	4.7E-1	5.0E-2	3.4E-5
Cm-243	W	4.8E-2	7.7E-1	7.0E-1	0.	2.2E-1	5.5E-2	3.8E-5
Cm-244	W	3.5E-2	5.5E-1	5.2E-1	0.	1.6E-1	5.5E-2	3.6E-5

surface, has been used to construct a graph of exposure rate (at one meter height above the soil surface) as a function of gamma energy for such a source. This graph has been presented in Figure A.6.

Exposure rates, E, for the radionuclides of interest in this study have been calculated from the expression:

$$E = K \cdot \sum f_i E_T$$

where f is the fraction of gamma photons of energy T per disintegration, E_T is the exposure rate factor obtained from Figure A.6 for energy T, and K is a proportionality constant which converts the exposure rate factor in HASL-195(15) to units of dose equivalent (mrem/year per Ci/m^3). As indicated in Figure A.6, K = 65.9 uR/hr per MeV/g-sec. In this report, it is assumed that one Roentgen equals one rem. The resultant annual external gamma dose conversion factors resulting from volume contaminated soil, denoted by DCF3, are presented in Table B-3.

B.2.4 Other Direct Exposure DCF's

The two remaining DCF's are the external exposure factors resulting from direct photon and electron radiation emanating from radionuclides on surface contaminated soil, and from immersion in uniformly contaminated air, these DCF's are denoted by DCF4 and DCF5, respectively.

In the past, the electron component (beta radiation) of the exposure was frequently neglected in comparison to the photon component (gamma radiation) of the exposure due to the comparative penetration capability of these radiations. For the direct radiation (volume) DCF's, this is the case since a few millimeters of soil is sufficient to stop most of the electron radiation from the radionuclides considered in this work. However, it is more accurate to include the electron component when the exposure is due to surface contaminated soil or to immersion in contaminated air.

TABLE B-3 . External Exposure Fundamental Dose Conversion Factors

	DCF-3 (mrem/year per Ci/m^3)	DCF-4 (mrem/year per Ci/m^2)	DCF-5 (mrem/year per Ci/m^3)
H-3	0.	0.	5.19E-05
Be-10	0.	2.36E-05	1.82E-03
C-14	0.	0.	4.46E-04
Cl-36	8.80E-11	9.18E-10	1.29E-07
Ca-41	0.	4.49E-07	2.45E-05
Fe-55	0.	2.67E-06	5.08E-05
Co-60	1.54E-05	3.84E-04	2.28E-02
Ni-59	6.20E-09	4.27E-06	5.98E-05
Ni-63	0.	0.	1.56E-04
Sr-90	3.06E-08	2.74E-05	1.76E-03
Nb-94	9.63E-06	9.90E-05	1.32E-02
Mo-93	0.	1.33E-05	1.34E-04
Tc-99	0.	0.	7.60E-04
I-129	1.92E-08	1.13E-05	6.86E-04
Cs-135	0.	0.	5.08E-04
Cs-137	3.50E-06	3.99E-05	1.53E-03
Eu-152	6.22E-06	2.71E-04	1.11E-02
Eu-154	8.07E-06	3.78E-04	1.32E-02
Re-187	0.	0.	0.
Pb-210	8.56E-09	2.27E-06	1.43E-05
Bi-207	9.37E-06	9.24E-05	1.29E-02
Ra-226	7.21E-06	9.47E-07	4.90E-05
Th-230	1.50E-09	6.12E-07	3.59E-06
Th-232	2.66E-05	2.28E-06	1.08E-04
U-233	0.	1.78E-06	5.16E-05
U-234	4.28E-10	2.88E-06	1.14E-04
U-235	1.50E-07	3.65E-05	1.59E-03
U-236	0.	2.72E-06	9.67E-05
U-238	5.16E-09	2.40E-06	8.57E-05
Np-237	6.56E-08	2.21E-05	8.40E-04
Pu-238	1.93E-11	3.18E-06	8.87E-05
Pu-239	9.39E-11	1.22E-06	5.17E-05
Pu-241	3.43E-13	0.	4.78E-05
Pu-242	0.	2.38E-06	6.93E-05
Am-241	7.71E-08	1.30E-05	3.80E-04
Am-243	1.86E-07	1.50E-05	6.09E-04
Cm-243	3.82E-07	4.02E-05	2.26E-03
Cm-244	5.64E-11	2.82E-06	7.23E-05

These DCF's have been calculated for various radionuclides for unit concentration in the biota access media -- i.e., pCi/m^2 of soil and pCi/m^3 of air.(16) For each exposure mode, DCF's for photons and electrons have been calculated for tissue-equivalent material at the body surface of an exposed individual. For internal body organs, only photons have been considered.(16) The DCF's obtained from reference 10, presented in Table B-3, have been utilized in this work when the exposure is due to surface contaminated soil (DCF-4), or to immersion in contaminated air (DCF-5).

B.3 Pathway Equations

This section presents the equations, the parameters, and the data utilized in the computation of the PDCF's. The components corresponding to each pathway are defined in Figure 2.5.

B.3.1 Uptake Factors

In order to calculate the PDCF's, several translocation parameters (also referred to as uptake factors or pathway parameters) are required. These parameters fall into two groups: those that depend only on the pathway being considered, and those that are radionuclide-specific. The parameters that depend only on the pathway are presented in Table B-4 together with the values assumed in this work and the references from which they were obtained.

The other group of parameters and pathway factors, which are radionuclide specific, are presented in Table B-5. The values utilized for the five radionuclide-specific transfer factors were obtained from the literature; a comparative compilation of these five factors is presented in Tables B-6 through B-10. Based on the pathway uptake parameters presented in Tables B-4 and B-5, several intermediate transfer parameters have been defined for the PDCF calculation. These intermediate parameters are defined and presented in Table B-11.

Table B-4 . Radionuclide Independent Parameters Used in Calculations

Symbol	Definition	Value	Reference
CY	Crop Yield per unit area	1 Kg/m^2	17
D	Soil Density	1600 Kg/m^3	17
f_2	Consumption of plants by man	190 Kg/year	3
f_3	Consumption of plants by animals	50 Kg/day	3
f_5	Consumption of animals by man	95 Kg/year	3
f_7	Consumption of milk by man	0.3 1/day	3
f_8	Consumption of water by beef cattle	50 1/day	3
f_8P	Consumption of water by milk cows	60 1/day	3
f_{11}	Consumption of water by man	370 1/year	3
f_{13}	Consumption of fish by man	6.9 Kg/year	3
$f_{13}P$	Consumption of seafood by man	1.0 Kg/year	3
f_{14}	Resuspension factor	8.5E-9 m^{-1}	18
f_{15}	Inhalation rate of man	8.0E+3 m^3/year	19
f_{18}	Areal mass available for resuspension (top 1 cm of soil)	16 Kg/m^2	17
R	The fraction of initial activity deposited as fallout or contaminated water that is retained by foliage.	0.25	17
RI	Irrigation rate	3.7E-3 m^3/m^2-day	17
S_1	Fraction of activity deposited on foliage removed per unit time by weathering mechanisms.	4.83E-2 day^{-1}	17
S_2	Fraction of activity deposited in the root zone removed per unit time.	7.6E-04 day^{-1}	17
	Settling velocity for elements		
V_1	other than iodine	8.0E-4 m/sec	17
V_2	for iodines	1.0E-2 m/sec	17
Z	Mass of soil in root zone	240 Kg/m^2	3

Table B-5 . Other Parameters Used in Calculations

Symbol	Definition	Units
C_a	Initial Air Concentration	1 pCi/m^3
C_s	Initial Soil Concentration	1 pCi/kg
C_{SA}	Initial Areal Soil Concentration	1 pCi/m^2
C_{SV}	Initial Volume Soil Concentration	1 pCi/m^3
C_w	Initial Water Concentration	1 pCi/m^3
DCF1	Fundamental DCF for Ingestion	See Table B-1
DCF2	Fundamental DCF for Ingestion	See Table B-2
DCF3	Fundamental DCF for External Exposure (Volume Source)	See Table B-3
DCF4	Fundamental DCF for External Exposure (Area Source)	See Table B-3
DCF5	Fundamental DCF for External Exposure (Air Immersion)	See Table B-3
f_1	Soil-to-Plant Transfer Factor (pCi/kg in fresh vegetation per pCi/kg in soil)	See Table B-6 Dimensionless
f_4	Feed or Water-to-Meat Transfer Factor (pCi/kg in meat per pCi/day ingested by beef cattle)	See Table B-7 day/kg
f_6	Feed or Water-to-Animal Product (Milk) Transfer Factor (pCi/l in milk per pCi/day ingested by cow)	See Table B-8 day/l
f_{12}	Water-to-Fish Transfer Factor (pCi/kg of fresh fish per pCi/l of water concentration)	See Table B-9 l/kg
f_{12}^P	Water-to-Freshwater Seafood Transfer Factor (pCi/kg of fresh seafood per pCi/l of water concentration)	See Table B-10 l/kg

TABLE B-6 . Soil-to Plant Transfer Factors (Dimensionless)

	Ref	Ref	Ref	Ref	Ref	Ref
Element	20	3	21	22	23	14
Hydrogen	4.8E+0[a]	4.8E+0			4.8E+0	
Beryllium	4.2E-4					
Carbon	5.5E+0	5.5E+0			5.5E+0	
Chlorine	5.0E+0					
Calcium	3.6E-2[b]					
Iron	6.6E-4	6.6E-4			6.6E-4	
Cobalt	9.4E-3	9.4E-3			9.4E-3	
Nickel	1.9E-2	1.9E-2			1.9E-2	
Strontium	1.7E-2	1.7E-2		2.9E-1	1.7E-2	
Niobium	9.4E-3	9.4E-3			9.4E-3	
Molybdenum	1.2E-1	1.2E-1			″	
Technetium	2.5E-1	2.5E-1		1.1E+0	2.5E-1	
Iodine	2.0E-2	2.0E-2		5.5E-2	2.0E-2	
Cesium	1.0E-2	1.0E-2		9.3E-3	1.9E-2	
Europium	2.5E-3					
Rhenium	2.5E-1					
Lead	6.8E-2		4.0E-3	3.9E-3		
Bismuth	1.5E-1					
Radium	3.1E-4		1.4E-2	6.2E-2		
Thorium	4.2E-3			3.5E-4		
Uranium	2.5E-3			2.9E-4	2.5E-3	
Neptunium	2.5E-3	2.5E-3			2.5E-3	
Plutonium	2.5E-4			2.0E-4	2.5E-4	5.6E-4
Americium	2.5E-4				2.5E-4	5.6E-3
Curium	2.5E-3				2.5E-3	

(a) Values selected in this report have been underlined.

(b) Calcium value of 3.7E-2 from reference 24 is utilized.

TABLE B-7 . Feed and Water-to-Meat Transfer Factors (day/kg)

Element	Ref 20	Ref 3	Ref 21	Ref 22	Ref 23	Ref 14
Hydrogen	1.2E-2(a)	1.2E-2				
Beryllium	1.0E-3					
Carbon	3.1E-2	3.1E-2				
Chlorine	8.0E-2					
Calcium	4.0E-3(b)					
Iron	4.0E-2	4.0E-2				
Cobalt	1.3E-2	1.3E-2				
Nickel	5.3E-2	5.3E-2				
Strontium	6.0E-4	6.0E-4		3.0E-4		
Niobium	2.8E-1	2.8E-1				
Molybdenum	8.0E-3	8.0E-3				
Technetium	4.0E-1	4.0E-1		8.7E-3		
Iodine	2.9E-3	2.9E-3		7.0E-3		
Cesium	4.0E-3	4.0E-3		1.4E-2		
Europium	4.8E-3					
Rhenium	8.0E-3					
Lead	2.9E-4		7.1E-4	9.1E-4		
Bismuth	1.3E-2					
Radium	3.4E-2		5.1E-4	5.0E-4		
Thorium	2.0E-4		2.0E-4	1.6E-6		
Uranium	3.4E-4			1.6E-6		
Neptunium	2.0E-4	2.0E-4				
Plutonium	1.4E-5			4.1E-7		3.9E-4
Americium	2.0E-4					3.9E-3
Curium	2.0E-4					

(a) Values selected in this report have been underlined.

(b) Calcium value of 4.0E-2 from reference 24 is utilized.

TABLE B-8 . Feed and Water-to-Milk Transfer Factors (day/kg)

Element	Ref 20	Ref 3	Ref 21	Ref 22	Ref 14	Ref 25
Hydrogen	1.0E-2(a)	1.0E-2				1.4E-2
Beryllium	1.0E-4					9.1E-7
Carbon	1.2E-2	1.2E-2				1.5E-2
Chlorine	5.0E-2					1.7E-2
Calcium	8.0E-3					1.1E-2
Iron	1.2E-3	1.2E-3				5.9E-5
Cobalt	1.0E-3	1.0E-3				2.0E-3
Nickel	6.7E-3	6.7E-3				1.0E-2
Strontium	8.0E-4	8.0E-4		2.4E-3		1.4E-3
Niobium	2.5E-3	2.5E-3				2.0E-2
Molybdenum	7.5E-3	7.5E-3				1.4E-3
Technetium	2.5E-2	2.5E-2		9.9E-3		
Iodine	6.0E-3	6.0E-3		1.0E-2		9.9E-3
Cesium	1.2E-2	1.2E-2		5.6E-3		7.1E-3
Europium	5.0E-6					2.0E-5
Rhenium	2.5E-2					1.3E-3
Lead	6.2E-4		1.2E-4	9.9E-5		2.6E-4
Bismuth	5.0E-4					5.0E-4
Radium	8.0E-3		5.9E-4	5.9E-4		4.5E-4
Thorium	5.0E-6			5.0E-6		5.0E-6
Uranium	5.0E-4			1.2E-4		6.1E-4
Neptunium	5.0E-6	5.0E-6				5.0E-6
Plutonium	2.0E-6			4.5E-8	<5.0E-4	1.0E-7
Americium	5.0E-6				<5.0E-3	2.0E-5
Curium	5.0E-6					2.0E-5

(a) Values selected in this report have been underlined.

TABLE B-9 . Water-to-Fresh Fish Transfer Factors (l/kg)

Element	Ref 20	Ref 3	Ref 21	Ref 22	Ref 23	Ref 14
Hydrogen	9.0E-1(a)	9.0E-1				
Beryllium	2.0E+0					
Carbon	4.6E+3	4.6E+3				
Chlorine	5.0E+1					
Calcium	4.0E+1					
Iron	1.0E+2	1.0E+2				
Cobalt	5.0E+1	5.0E+1				
Nickel	1.0E+2	1.0E+2				
Strontium	3.0E+1	3.0E+1				
Niobium	3.0E+4	3.0E+4				
Molybdenum	1.0E+1	1.0E+1				
Technetium	1.5E+1	1.5E+1				
Iodine	1.5E+1	1.5E+1				
Cesium	2.0E+3	2.0E+3				
Europium	2.5E+1					
Rhenium	1.2E+2					
Lead	1.0E+2					
Bismuth	1.5E+1					
Radium	5.0E+1					
Thorium	3.0E+1					
Uranium	2.0E+0					
Neptunium	1.0E+1	1.0E+1				
Plutonium	3.5E+0					2.5E+1
Americium	2.5E+1					2.5E+2
Curium	2.5E+1					

(a) Values selected in this report have been underlined.

TABLE B-10. Water-to-Freshwater Seafood Transfer Factors (l/kg)

Element	Ref 20	Ref 3	Ref 21	Ref 22	Ref 23	Ref 14
Hydrogen	9.0E-1(a)	9.0E-1				
Beryllium	1.0E+1					
Carbon	9.1E+3	9.1E+3				
Chlorine	1.0E+2					
Calcium	3.3E+2					
Iron	3.2E+3	3.2E+3				
Cobalt	2.0E+2	2.0E+2				
Nickel	1.0E+2	1.0E+2				
Strontium	1.0E+2	1.0E+2				
Niobium	1.0E+2	1.0E+2				
Molybdenum	1.0E+1	1.0E+1				
Technetium	5.0E+0	5.0E+0				
Iodine	5.0E+0	5.0E+0				
Cesium	1.0E+2	1.0E+2				
Europium	1.0E+3					
Rhenium	6.0E+1					
Lead	1.0E+2					
Bismuth	2.4E+1					
Radium	2.5E+2					
Thorium	5.0E+2					
Uranium	6.0E+1					
Neptunium	4.0E+2	4.0E+2				
Plutonium	1.0E+2					
Americium	1.0E+3					
Curium	1.0E+3					

(a) Values selected in this report have been underlined.

Table B-11 . Intermediate Parameters Used in Calculations

Symbol	Transfer Factor	Description
P_1	f_1*f_2	Soil-Plant-Man
P_2	$f_1*f_3*f_4*f_5/365$	Soil-Plant-Animal-Man
P_3	$f_1*f_3*f_6*f_7$	Soil-Plant-Animal-Product-Man
PT	$P_1+P_2+P_3$	Total Soil-to-Plant-to-Man
P_1P	f_2	Plant-Man
P_2P	$f_3*f_4*f_5/365$	Plant-Animal-Man
P_3P	$f_3*f_6*f_7$	Plant-Animal-Product-Man
PTP	$P_1P+P_2P+P_3P$	Total Plant-to-Man
F_1	$f_8*f_4*f_5$	Water-Animal-Man
F_2	$f_8P*f_6*f_7*365$	Water-Animal-Product-Man
F_3	f_{11}	Water-Man
FT	$F_1+F_2+F_3$	Total Water-to-Man
F_{12_1}	$f_{12}*f_{13}$	Water-Fish-Man
F_{12_2}	$f_{12}P*f_{13}P$	Water-Seafood-Man
F_{12}	$F_{12_1}+F_{12_2}$	Total Seafood-to-Man
D_1	$86400*V/(S_2*Z)$	Soil Deposition by Fallout
D_2	$86400*RV/S_1$	Foliar Deposition by Fallout
W_1	$RI/(S_2*Z)$	Soil Deposition by Irrigation
W_2	$R*RI/S_1$	Foliar Deposition by Irrigation
	86400	seconds/day
	365	days/year

B.3.2 Calculational Procedure

The equations utilized to calculate the PDCF's are summarized in Table B-12. Some of the PDCF's are calculated using a single equation since common factors are present in the individual uptake pathway components; however, some PDCF's require multiple equations.

All of these equations are basic pathway equations that bring together the calculational components contributing to the human dose. A detailed treatment of these pathway equations may be found in Regulatory Guide 1.109.(3,20)

The fundamental equation for the calculation of total pathway dose conversion factors for man from radionuclides in the environment via specific exposure scenarios can be given as:

$$D_{irps} = \sum_{i=1}^{N} C_{ips} \, f_{ips} \, DCF_{irp} \qquad (B.1)$$

where:

D_{irps} = the total pathway dose conversion factor (50-year dose committment in mrem), specific to organ r from nuclide i from pathway p via scenario s;

N = the total number of pathways in the scenario,

C_{ips} = the concentration of nuclide i in the medium of pathway p via scenario s (in pCi/m^3, pCi/kg, or pCi/m^2),

f_{ips} = the pathway usage factor of nuclide i of pathway p via scenario s which is considered in the calculation of the accumulated radiation dose conversion factor to man; and

DCF_{irp} = the fundamental dose conversion factor, a value specific to a given nuclide i, pathway p, and organ r which is used to calculate radiation dose commitments.

Table B-12. Equations Used in Calculations

PDCF-1 = (6) + (9)
PDCF-2 = (7)
PDCF-3 = (8)
PDCF-4 = (1)
PDCF-5 = (2)
PDCF-6 = (3) + (10)
PDCF-7 = (3) + (4) + (10)
PDCF-8 = (5) + (8)

(1) C_s*(PT/D)*DCF1
(2) C_s*DCF3
(3) C_w*(W_1*PT+(W_2/CY)*PTP+FT/1000)*DCF1
(4) C_w*(f_{12}/1000)*DCF1
(5) C_a*D_1*f_{18}*(f_{14}*(f_{15}*DCF2+DCF5)+DCF4)
(6) C_a*D_1*f_{18}*(f_{14}*(f_{15}*DCF2+DCF5)+DCF4)*0.242
(7) C_a*(f_{15}*DCF2+DCF5+(D_1*PT+(D_2/CY)*F*PTP)*DCF1)*0.242
(8) C_a*(f_{15}*DCF2+DCF5+(D_1*PT+(D_2/CY)*F*PTP)*DCF1)
(9) C_a*(DCF5+f_{15}*DCF2)
(10) C_w*W_1*f_{18}*(f_{14}*(f_{15}*DCF2+DCF4)+DCF5)

B.4 Computer Code DOSE

A listing of the code utilized to calculate the PDCF's presented and used in the main body of the report is attached. The program is written in Fortran IV for a CDC 6600 computer. The program is interactive -- i.e., it is executed in a time-sharing mode, and it asks questions and requests answers by the person running the program. All the uptake factors and translocation parameters have been incorporated into the data statements at the beginning of the program. It requires a data tape, called TAPE1 containing the fundamental dose conversion factors presented in this appendix. Using this program, PDCF's for up to 39 radionuclides may be calculated. In addition, it contains the option to change the fundamental dose conversion factors for any of these radionuclides.

```
      PROGRAM DOSE(INPUT,OUTPUT,TAPE1)
      DIMENSION NP(8),ISCN(3,8),DCF(39,7,7),NNUC(39),DOSE(8,7)
      DIMENSION ORGAN(7),SCN(8),F1(39),F4(39),F6(39)
      DIMENSION F12(39),F12P(39)
      DATA ISCN/5,9,0,7,0,0,8,0,0,1,0,0,2,0,0,3,10,0,3,4,10,6,8,0/
      DATA NP/2,1,1,1,1,2,3,2/
      DATA ORGAN/10HTOTAL BODY,10H   BONE   ,10H   LIVER  ,
      10H  THYROID ,10H  KIDNEY  ,10H   LUNG   ,10H  GI-LLI  /
      DATA NNUC/10HH-3        ,10HBE-10     ,10HC-14      ,10HCL-36     ,
                10HCA-41      ,10HFE-55     ,10HCO-60     ,10HNI-59     ,
                10HNI-63      ,10HSR-90     ,10HY-90      ,10HNB-94     ,
                10HMO-93      ,10HTC-99     ,10HI-129     ,10HCS-135    ,
                10HCS-137     ,10HEU-152    ,10HEU-154    ,10HRE-187    ,
                10HPB-210     ,10HBI-207    ,10HRA-226    ,10HTH-230    ,
                10HTH-232     ,10HU-233     ,10HU-234     ,10HU-235     ,
                10HU-236      ,10HU-238     ,10HNP-237    ,10HPU-238    ,
                10HPU-239     ,10HPU-241    ,10HPU-242    ,10HAM-241    ,
                10HAM-243     ,10HCM-243    ,10HCM-244    /
      DATA SCN/10HACCIDENT  ,10HCONSTRUCT ,10HAGRICULTUR,10HFOOD      ,
      10HDIR. GAMMA,10HWELL WATER,10HSURF-WATER,10HATMOSPHERE/
      DATA V1,V2,S1,S2,Z,RI,R/.01,.0008,.0483,.000765,240.,.0037,.25/
      DATA CY,D,F,F2,F3,F5,F7,F8,F8P/1.,1600.,1.,190.,50.,95.,.3,50.,60./
      DATA F11,F13,F14,F15,F18/370.,6.9,8.5E-9,8000.,16./
      DATA F1/4.8,.00042,5.5,5.0,.037,.00066,.0094,
      .019,.019,.29,.0025,.0094,.12,1.1,.055,.0093,.0093,.0025,.0025,
      .25,.004,.15,.014,.0042,.0042,5*.0025,.0025,4*.00056,2*.0056,
      .0025,.0025/,F13P/1./
      DATA F4/.012,.001,.031,.08,.04,.04,.013,.053,.053,3.0E-4,
      .0046,.28,.008,8.7E-3,7.0E-3,2*1.4E-2,.0048,.0048,.008,.00071,
      .013,.00051,2*2.E-4,5*3.4E-4,2.E-4,4*3.9E-4,2*3.9E-3,2*2.E-4/
      DATA F6/.01,.00000091,.012,.017,.011,.000059,
      .001,.0067,.0067,2.4E-3,.0000159,.0025,.0014,9.9E-3,.001,2*5.6E-3,
      .00002,.00002,.0013,.00012,.0005,.00059,2*.000005,5*.00061,
      .000005,4*2.0E-6,4*5.0E-6/
      DATA F12/.9,2.,4600.,50.,40.,100.,50.,100.,100.,
      30.,25.,30000.,10.,2*15.,2000.,2000.,25.,25.,120.,100.,15.,50.,
      30.,30.,5*2.,10.,4*25.,250.,250.,25.,25./
      DATA F12P/.9,10.,9100.,100.,330.,3200.,200.,100.,100.,
      100.,1000.,100.,10.,2*5.,100.,100.,1000.,1000.,60.,100.,24.,
      250.,500.,500.,5*60.,400.,4*100.,2*1000.,2*1000./
      DO 90 K=1,2
      READ(1,701)AF
   90 READ(1,700)((DCF(I,J,K),J=1,7),I=1,39)
      DO 95 K=3,5
      READ(1,701)AF
   95 READ(1,700)(DCF(I,1,K),I=1,39)
  700 FORMAT(7E9.2)
  701 FORMAT(A10)
      PRINT,*   *
      PRINT,*THIS PROGRAM REQUIRES AN INITIAL INPUT OF THE NUCLIDE*
      PRINT,*NAME. AFTER THIS YOU INDICATE WHETHER YOU WISH THE DOSE*
      PRINT,*CONVERSION FACTORS TO BE READ IN THRU TAPE 1 OR*
      PRINT,*TO ENTER THESE VALUES INTERACTIVELY THRU THE*
      PRINT,*COMPUTER TERMINAL. (0 = TAPE 1 ,  1 = INTERACTIVE)*
      PRINT,*   *
      PRINT,*IF INTERACTIVE:*
      PRINT,*NEXT 2 LINES ARE DOSE CONVERSION FACTORS FOR 7 ORGANS.*
      PRINT,*THESE ORGANS ARE:TOTAL BODY,BONE,LIVER,THYROID,KIDNEY,*,
      PRINT,*LUNG,AND GI-LLI.*
      PRINT,*   LINE 2:DCF1'S- INGESTION            MREM/50YR PER pCI*,
      PRINT,* INGESTED IN FIRST YEAR*
      PRINT,*   LINE 3:DCF2'S- INHALATION           MREM/50YR PER pCI*,
      PRINT,* INHALED IN FIRST YEAR*
      PRINT,*THESE DCF'S ARE INPUT 7 PER LINE (ONE FOR EACH ORGAN) *,
      PRINT,*SEPERATED BY COMMAS.*
      PRINT,*NEXT 3 LINES ARE DIRECT GAMMA DOSE CONVERSION FACTORS*
      PRINT,*ONLY ONE NUMBER FOR WHOLE BODY REGUIRED IN EACH CASE.*
      PRINT,*(SAME DCF IS USED FOR ALL OTHER ORGANS.)*
      PRINT,*   LINE 4:DCF3'S- DIRECT GAMMA(VOLUME) MREM/YR PER pCI/M^3*
      PRINT,*   LINE 5:DCF4'S- DIRECT GAMMA(AREA)   MREM/YR PER pCI/M^2*
      PRINT,*   LINE 6:DCF5'S- DIRECT GAMMA(AIR)    MREM/YR PER pCI/M^3*
      PRINT,*     * $ PRINT,*     * $ PRINT,*     *
      PRINT,*TYPE 'STOP' FOR NUCLIDE TO TERMINATE PROGRAM*
      PRINT,*   * $ PRINT,*   * $ PRINT,*   *
  110 PRINT,*NUCLIDE *,
      READ 500,NUKE
      DO 50 I=1,39
      IF(NUKE.EQ.NNUC(I)) GO TO 55
   50 CONTINUE
      PRINT,*NO NUCLIDE OF THAT NAME FOUND*
      GO TO 110
   55 NUC=I
      PRINT,*INTERACTIVE INPUT*, $ READ,IQ
      IF(IQ.EQ.0) GO TO 60
      PRINT,*DCF1'S: *,
      READ,(DCF(NUC,J,1),J=1,7)
      PRINT,*DCF2'S: *,
      READ,(DCF(NUC,J,2),J=1,7)
      PRINT,*DCF3: *,
      READ,DCF(NUC,1,3)
      PRINT,*DCF4: *,
      READ,DCF(NUC,1,4)
      PRINT,*DCF5: *,
      READ,DCF(NUC,1,5)
   60 DO 65 I=3,5
      DO 65 J=2,7
   65 DCF(NUC,J,I)=DCF(NUC,1,I)
      S=1. $ A=1. $ W=1.
      CS=S/W $ CSV=S
      CA=A
      CW=W   $ CWP=CW*0.001
      P1=F1(NUC)*F2 $ P2=F1(NUC)*F3*F4(NUC)/365.*F5
      P3=F1(NUC)*F3*F6(NUC)*F7
      PT=P1+P2+P3 $ PTP=PT/F1(NUC)
      FT=F8*F4(NUC)*F5+F8P*F6(NUC)*F7*365.+F11
      F12N=F12(NUC)*F13+F12P(NUC)*F13P
      V=V2 $ IF(NUC.EQ.15) V=V1
      D1=86400.*V/(S2*Z)  $ D2=86400.*R*V/S1
      W1=RI/(S2*Z) $ W2=R*RI/S1
      DO 200 I=1,8
      DO 200 IO=1,7
      N=NP(I) $ A1=0.
      DO 100 J=1,N
      IP=ISCN(J,I)
      GO TO (1,2,3,4,5,6,7,8,9,10),IP
    1 A1=A1+CS*PT*DCF(NUC,IO,1)                                   $ GO TO 100
    2 A1=A1+CSV*DCF(NUC,IO,3)                                     $ GO TO 100
    3 A1=A1+(CW*(W1*PT+(W2/CY)*PTP)+CWP*FT)*DCF(NUC,IO,1)         $ GO TO 100
    4 A1=A1+CWP*F12N*DCF(NUC,IO,1)                                $ GO TO 100
    5 A1=A1+CA*D1*F18*(F14*(F15*DCF(NUC,IO,2)+DCF(NUC,IO,5))+
+     DCF(NUC,IO,4))                                              $ GO TO 100
    6 A1=A1+CA*D1*F18*(F14*(F15*DCF(NUC,IO,2)+DCF(NUC,IO,5))+
+     DCF(NUC,IO,4))*0.242                                        $ GO TO 100
    7 A1=A1+CA*(DCF(NUC,IO,5)+F15*DCF(NUC,IO,2))+
+     CA*(D1*PT+(D2/CY)*F*PTP)*DCF(NUC,IO,1)*.242                 $ GO TO 100
    8 A1=A1+CA*(DCF(NUC,IO,5)+F15*DCF(NUC,IO,2))+
+     CA*(D1*PT+(D2/CY)*F*PTP)*DCF(NUC,IO,1)                      $ GO TO 100
    9 A1=A1+CA*(DCF(NUC,IO,5)+F15*DCF(NUC,IO,2))                  $ GO TO 100
   10 A1=A1+CW*W1*F18*(F14*(F15*DCF(NUC,IO,2)+DCF(NUC,IO,5))+
+     DCF(NUC,IO,4))
  100 CONTINUE
      DOSE(I,IO)=A1*1.E+12
  200 CONTINUE
      PRINT 600,NNUC(NUC)
      PRINT 610,(ORGAN(J),J=1,7)
      PRINT 620,(SCN(I),(DOSE(I,J),J=1,7),I=1,8)
      PRINT 630
      GO TO 110
  500 FORMAT(A10)
  600 FORMAT(//*NUCLIDE: *A10/)
  610 FORMAT(10X,7A10)
  620 FORMAT(A10,7E10.3)
  630 FORMAT(///)
  999 STOP
      END

---------------------------------------------------------------------------

                ----THE END----


STOP.
RDY*
```

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APPENDIX C

REFERENCE DISPOSAL LOCATIONS

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APPENDIX C : Reference Disposal Locations

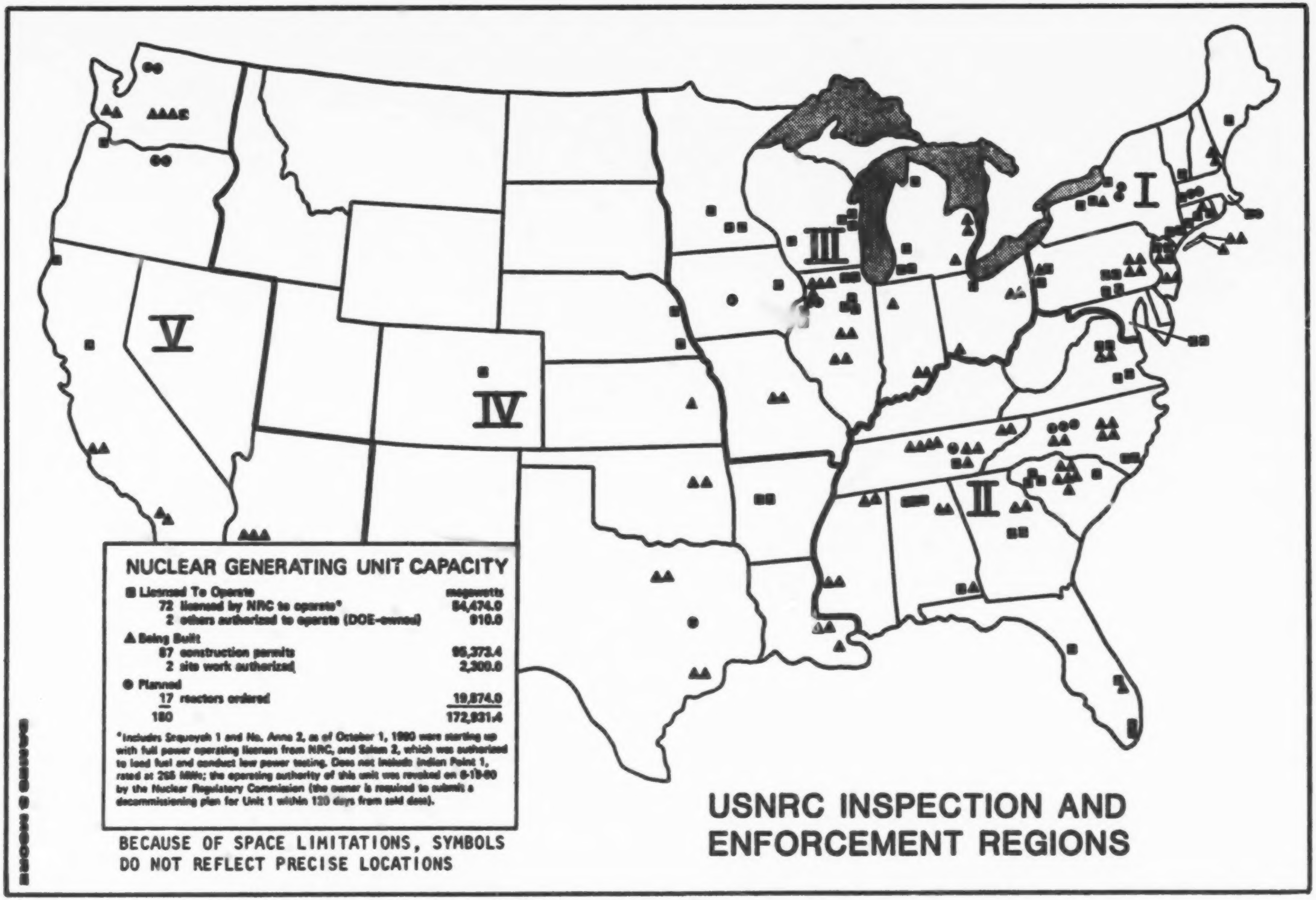
This appendix presents the environmental characteristics of four hypothetical regional disposal facility sites as well as the general disposal facility design for these sites. As shown in Figure C.1, the conterminous U.S. has been divided into four regions with boundaries based on those for U.S. NRC Regions. These waste generating regions will be referred to in this appendix as the northeast (Region 1), southeast (Region II), midwest (Region III), and western regions (Regions IV plus V). Each of these regions are projected to generate upto one million m^3 of LLW between the years 1980 and 2000.(1)

Within each region a hypothetical disposal facility is assumed to be located at a site having characteristics which are consistent with: (a) the basic disposal facility siting considerations presented in reference 2 and (b) the generic environmental characteristics within that geographic region. These regional sites are described in Section C.1. A description of the disposal facilities assumed to be situated at each of these sites are presented in Section C.2. Finally, the various environmental parameters associated with the regional sites are summarized in Section C.3.

C.1 Regional Site Descriptions

This section provides a brief description of four hypothetical regional sites: a northeastern site, a southeastern site (which is taken to be the reference disposal facility site discussed in the main body of the report), a midwestern site, and a southwestern site. The regional site descriptions are meant to be typical of environmental characteristics of the regions (not necessarily the "best" site that could be located within a region) and have been developed from a number of sources. Thus the regional site descriptions should not be interpreted as representing any existing or possibly planned disposal facility, or any specific location within the regions.

FIGURE C.1



NUCLEAR GENERATING UNIT CAPACITY

		megawatts
■ Licensed To Operate		
72	licensed by NRC to operate*	54,474.0
2	others authorized to operate (DOE-owned)	910.0
▲ Being Built		
87	construction permits	95,373.4
2	site work authorized	2,300.0
● Planned		
17	reactors ordered	19,874.0
180		172,931.4

*Includes Sequoyah 1 and No. Anna 2, as of October 1, 1980 were starting up with full power operating licenses from NRC, and Salem 2, which was authorized to load fuel and conduct low power testing. Does not include Indian Point 1, rated at 265 MWe; the operating authority of this unit was revoked on 6-19-80 by the Nuclear Regulatory Commission (the owner is required to submit a decommissioning plan for Unit 1 within 120 days from said date).

BECAUSE OF SPACE LIMITATIONS, SYMBOLS DO NOT REFLECT PRECISE LOCATIONS

USNRC INSPECTION AND ENFORCEMENT REGIONS

C.1.1 Northeastern Site

The Northeastern facility site is assumed to be located within the Appalachian Upland portion of the Appalachian Plateau physiographic province. A general topographic map of the site is presented in Figure C.2.

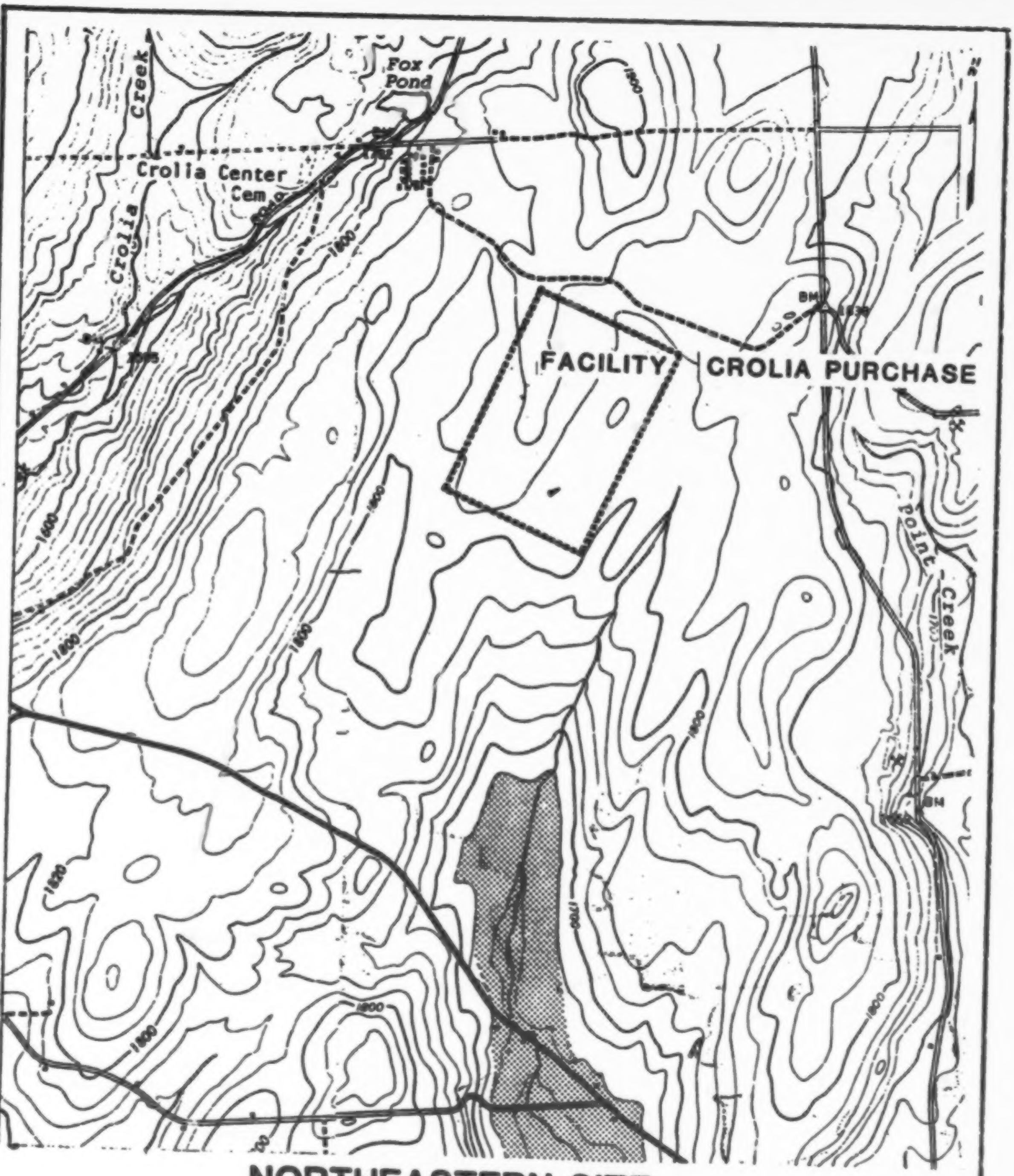
The area has been reworked by erosional and depositional forces associated with glacial and post-glacial activities. The disposal facility site is on an upland area, having an average elevation of about 555 m (1820 ft) above mean sea level (msl), and slopes to the south at a rate of about 3%. The drainage from the site flows into the headwaters of Point Creek.

Geology

Throughout most of the Appalachian upland, the bedrock is underlain by unconsolidated deposits of glacial origin. The thickness of these units is generally greater in the lowlands and valleys, gradually thinning out over the upland regions. The material properties of the deposits are highly variable.

The site is underlain by approximately 9 to 23 m (30 to 75 ft) of compact glacial till frequently referred to as hardpan. Thin and discontinuous interbedded layers of sand and gravel are observed locally in the area. Coarser-grained sediments are principally found in valleys and lowlands, and are associated with stream channels.

Underlying the glacial mantle are flat lying rocks of upper Devonian Age belonging to the Schaffer Group. These rocks consist of marine, black, and gray shales and siltstones, with some thin sandstone layers. The regional dip of the strata is to the south-southwest at a rate of about 2%. A westnorthwest-eastsoutheast geologic profile of the site area is shown on Figure C.3.


Fox Pond
Crolia Creek
Crolia Center Cem
FACILITY
CROLIA PURCHASE
BM
Point Creek
1800
1820
1700

NORTHEASTERN SITE TOPOGRAPHIC MAP

0 500 1000
SCALE IN METERS

0 1000 2000 3000
SCALE IN FEET

KEY:

▨ 500 YEAR FLOODWAY
CONTOURS IN FEET - 20 FOOT INTERVALS

DAMES & MOORE

FIGURE C.2

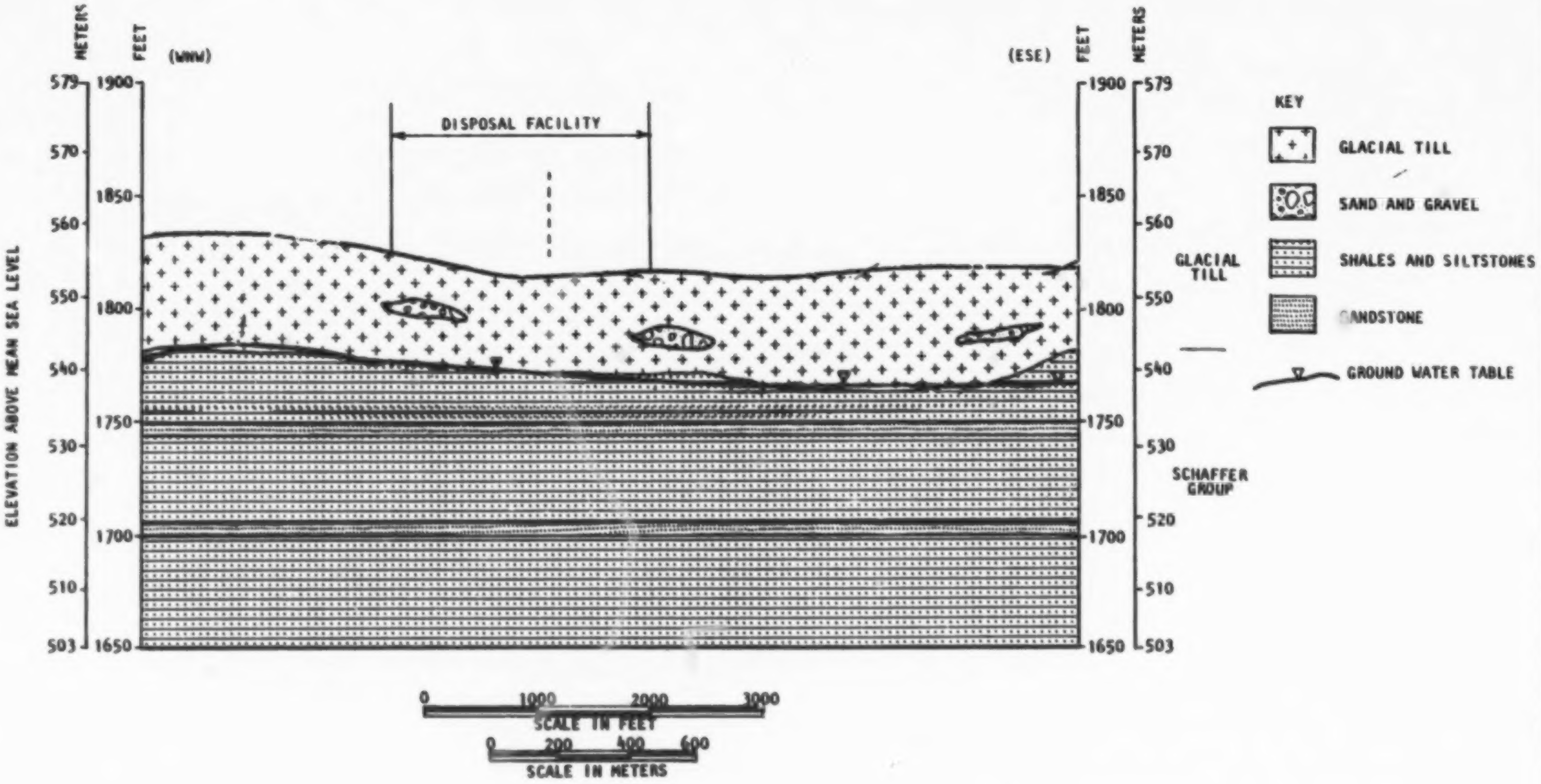

METERS
FEET
(WNW)
(ESE)
FEET
METERS
579
570
560
550
540
530
520
510
503
1900
1850
1800
1750
1700
1650
ELEVATION ABOVE MEAN SEA LEVEL
DISPOSAL FACILITY
GLACIAL TILL
SCHAFFER GROUP
KEY
GLACIAL TILL
SAND AND GRAVEL
SHALES AND SILTSTONES
SANDSTONE
GROUND WATER TABLE
0
1000
2000
3000
SCALE IN FEET
0
200
400
600
SCALE IN METERS

FIGURE C.3

GEOLOGIC PROFILE OF THE NORTHEASTERN SITE

The northeast site falls within one of the more tectonically stable regions of the northeast. The site location has been estimated to have a peak horizontal ground acceleration of 0.04 g, with a recurrance interval of more than 500 years. Based on available data, no capable faults are known to underlie the site or lie within 5 miles of the site.

Soils

The site area is covered by silty loams with an underlying brittle, dense fragipan. The predominant soil types belong to the Brickton, Warren, Chitta and Highland series. The parent material consists of acidic, low-lime-content, dense glacial till.

The site has slopes ranging from nearly level to moderately rolling grades, and the runoff potentials are correspondingly variable. The soils are deep and generally poorly drained. Permeabilities for the uppermost foot of soils are moderate, ranging from 15 to 50 mm per hour (0.6 to 2 inches per hour). However, the dense silty fragipan subsoil is of considerable thickness and is highly impervious, affording low permeabilities ranging between less than 1.5 to 5 mm (0.06 and 0.2 inches) per hour.

The soil is strongly acidic, especially in the topsoil layer. The plentiful root material in the upper layers contribute to the relatively high organic matter composition. In general, available nitrogen is high, with a moderate phosphorus and potassium content. The low lime content of the glacial till might indicate a correspondingly low calcium content.

Ground Water

The ground water generally occurs where the bedrock and glacial till meet. The depth to ground water at the site averages about 12 meters

(39 ft). The amount of groundwater available in the local upland area in which the site is located is largely limited to that which reaches the zone of saturation from precipitation falling upgradient of the site. This recharge quantity is small because of the low permeability of the till, and the heavily vegetated nature of the land surface which acts to hold water in the surficial organic matter affording greater loss via evapotranspiration. Recharge in these areas is limited, ranging from 5 to 50 mm (0.2 to 2 inches) per year.

Groundwater occurrence in the bedrock is limited to secondary openings along fracture zones and bedding planes. Generally, the fine-grained character associated with the shales and siltstones inhibits water movement. Rocks of this type typically have an upper permeability of about 4.72×10^{-7} to 4.72×10^{-5} cm/sec (0.01 to 1.0 gallons/day/ft^2 - gpd/ft^2). Movement in the intergranular pore spaces of the sandstone layers will be somewhat greater.

Groundwater flow is to the south, following the local topography, and enters the unconsolidated deposits at erosional interfaces. As stated previously, till is not a good water-bearing unit. The permeability of this material is on the order of 4.72×10^{-8} to 4.72×10^{-9} cm/sec (0.001 to 0.0001 gpd/ft^2). Where coarse-grained deposits are encountered, the permeability increases considerably, with values ranging from 4.72×10^{-2} to 4.72 cm/sec (1,000 to 10,000 gpd/ft^2). Most of the recharge entering at the site follows the hydraulic gradient to the south and is discharged as base flow into the headwaters of Point Creek which is about 1000 m (3280 ft) away.

Groundwater usage in this rural setting is very low. Pumpage is limited to widely scattered wells serving as domestic supplies to local homes and farmsteads. Most of these rural supplies are obtained from bedrock wells, 30 to 61 m (100 to 200 ft) in depth, although some of the water comes from seepage from the overlying deposits around the well casings. The average yields range between 23 to 30 liters per minute (6 to 10 gpm).

The quality of ground water in the unconsolidated deposits and upper shale units is generally good. Occasional samples collected in the upper shales were found to be high in total dissolved solids and hardness; however, average values are relatively low. Water in the unconsolidated deposits tends to reflect the influence of the underlying bedrock. In general, water from the deep gravel deposits is high in iron, and water from shallow gravel deposits is very hard.

Surface Water

The site is located in the once glaciated region of the Brokill Mountains. The rolling terrain is typical of the region, the result of glacial scour and fill. The drainage basin in which the site is located covers 7.36 km^2, with a coarse drainage density of 0.5 (dimensionless). Total stream length above the site is 2286 m (7500 ft).

The site vicinity is generally sloping to the south with total vegetative cover. The surface soils and vegetation allow for considerable retention of precipitation; only 20 to 30 percent of precipitation becomes surface runoff. A strong correlation exists between stream discharge and precipitation in the basin. Mean annual discharge at the outlet of the basin is 0.99 m^3/s (35 cfs), but a wide variation in flow occurs throughout the year. Analysis of the unit hydrograph indicates that while peak discharge in the stream occurs within 30 minutes of rainfall commencement, recession of the flow takes up to 30 hours. This variation is likely due to the base flow sustained by and fair weather runoff derived from groundwater.

Saturation of the lower basin area occurs during high intensity precipitation events, causing return flow. The maximum discharge of a 500 year flow is estimated to be on the order of 368 m^3/s. The floodway of such a flow is delineated on Figure C-2. As can be seen, the site is located well above the floodway.

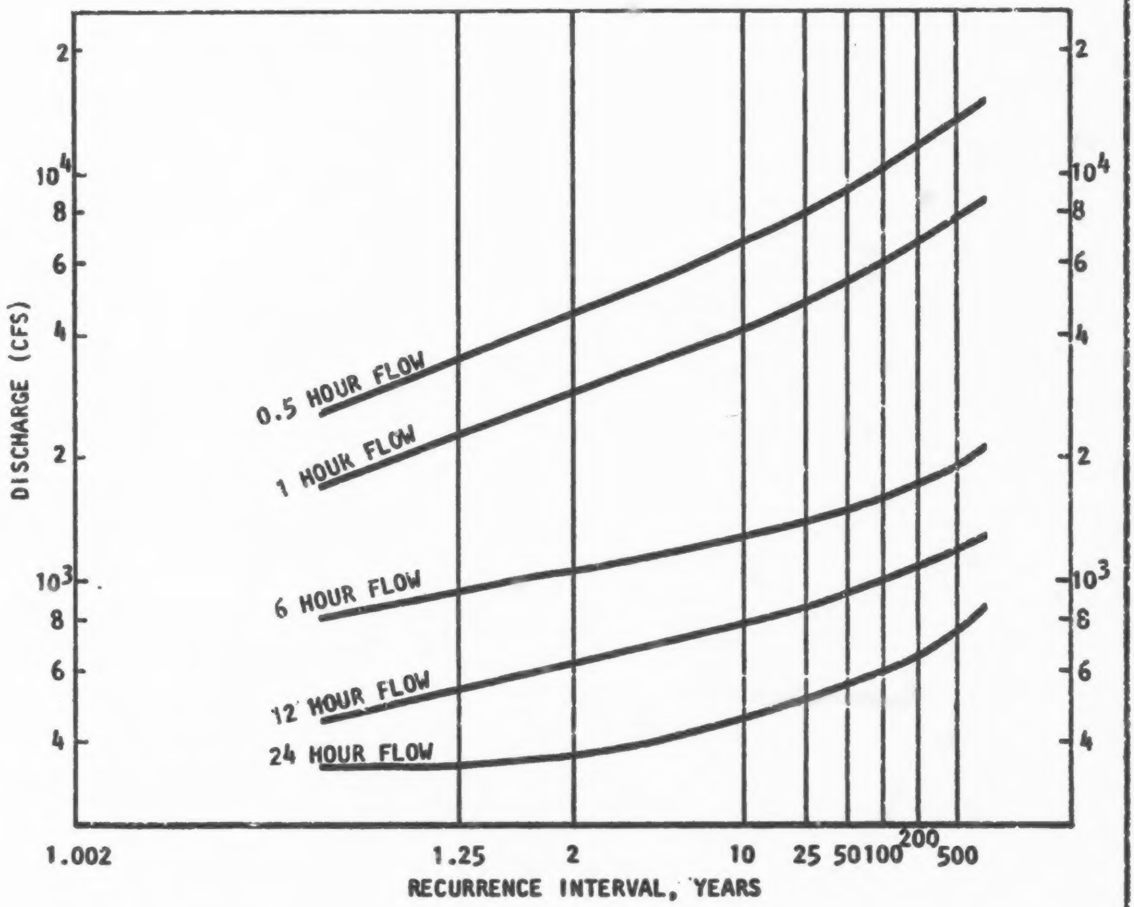
Development of the site will tend to reduce the infiltration area of the basin, reduce the time to peak discharge and increase the flood stage of the stream. Facility operations such as placement of impervious cover materials and clearing of vegetation are expected to increase the runoff by approximately 60% by the time the facility is closed. This increased runoff, however, will not result in increased potential for site flooding. Flow recurrance intervals for the location are shown in Figure C.4.

Meteorology

The climate in the area of the northeastern site is classified as humid continental, characterized by wide variations in seasonal precipitation and temperature. Moisture sources for precipitation are obtained from the southerly flow of Gulf air during the summer, cyclones that originate in the Great Lakes, and Atlantic coast systems. Precipitation is uniformly distributed over the year with the greatest average monthly amounts occuring during April through September in the form of thunder showers. The average annual precipitation is approximately 1034 mm (41 in). Precipitation event recurrance intervals for the location are shown in Figure C.5.

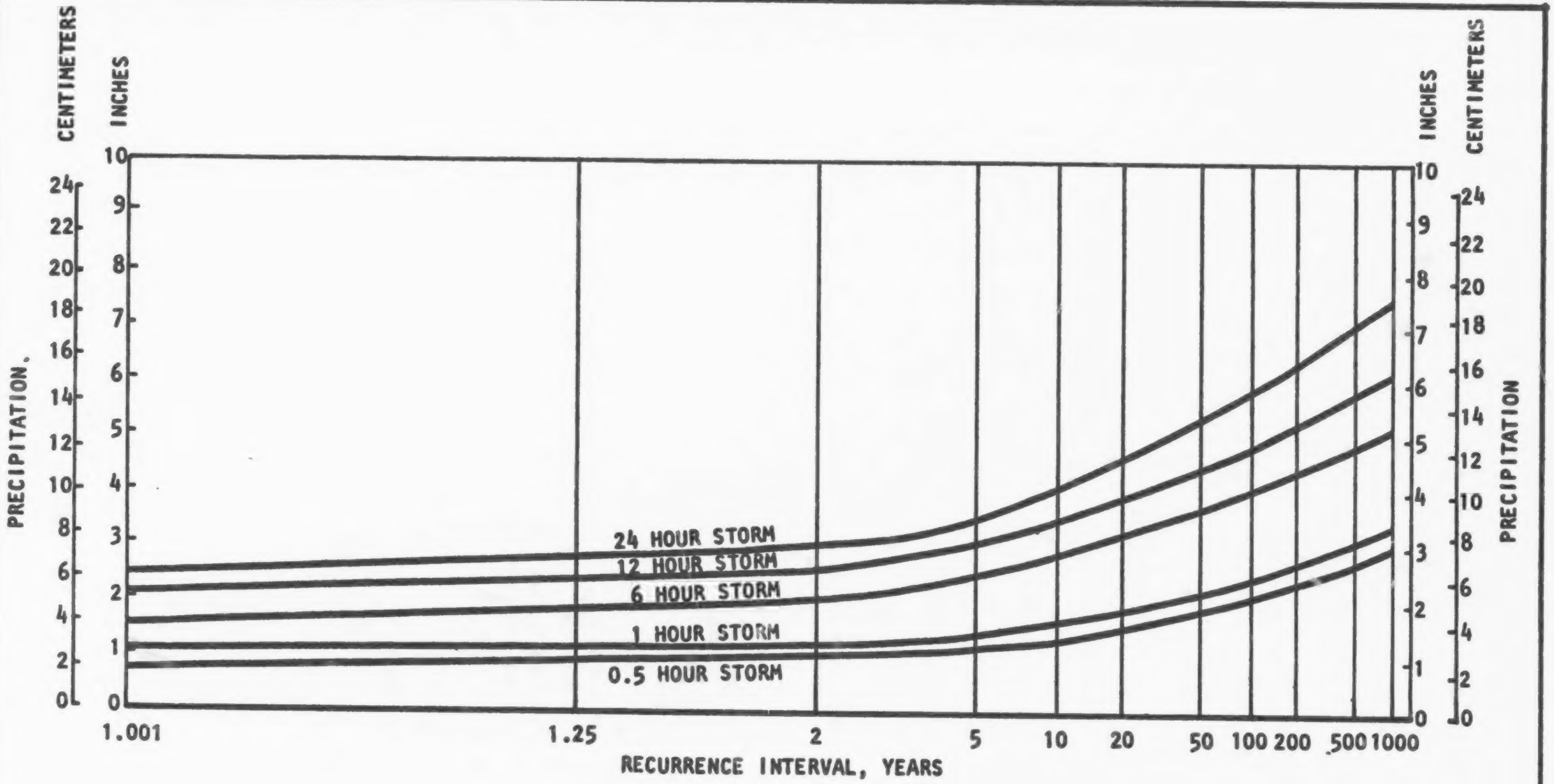
The area is characterized by distinct seasonal temperature variations. Winters are predominantly cold with maximum temperatures ranging from 0 to 20°C (32 to 68°F), and nightime minimums of from -9 to -7°C (15 to 20°F). The temperatures are generally mild during June through August and maximum temperatures average from 24 to 26°C (75 to 79°F). The mean annual temperature for the area is 8°C (46°F). Mean monthly temperatures, and the average of the monthly maximum and minimum temperatures in the vicinity are shown in Figure C.6.

The prevailing wind direction is southerly from May through November and westerly during the winter and early spring. The average wind speeds during these periods are 15.6 and 17.8 km/hr (8.4 and 9.6



FLOW RECURRENCE INTERVALS FOR THE NORTHEASTERN SITE

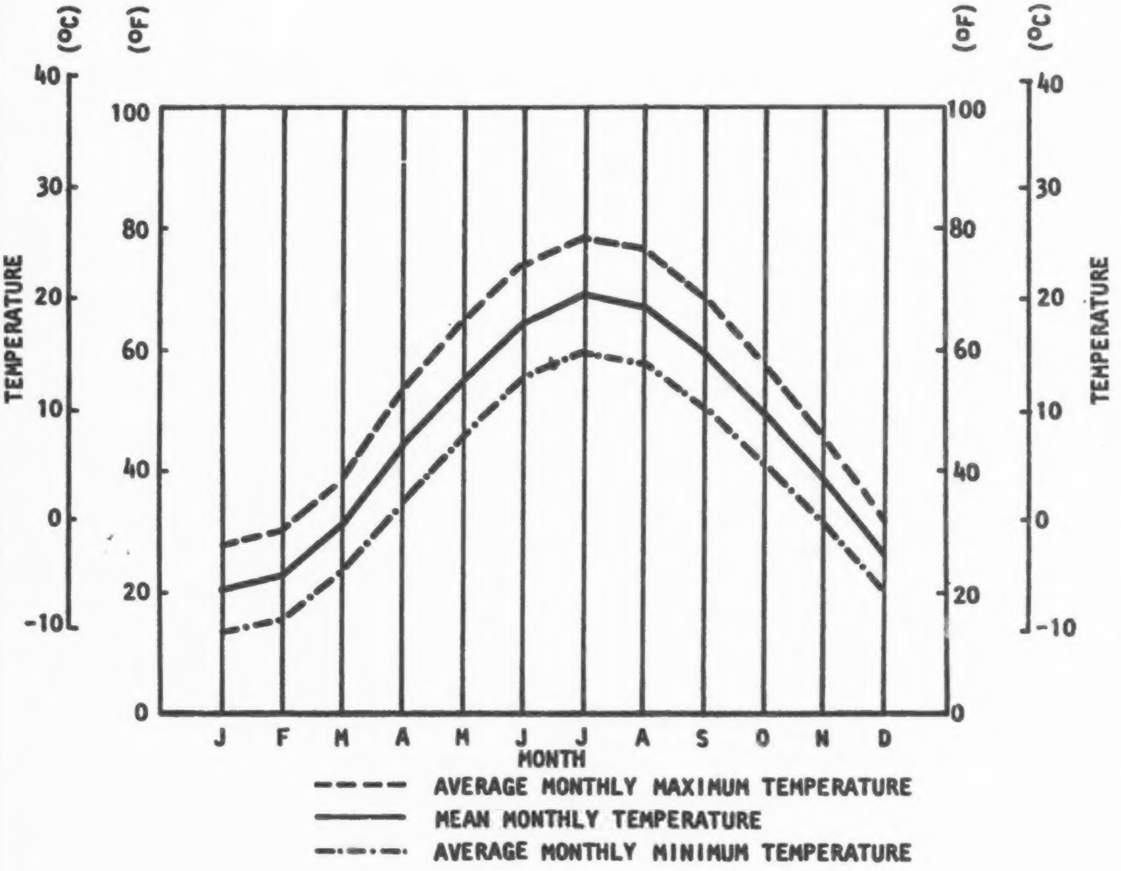
FIGURE C.4



PRECIPITATION EVENT RECURRENCE INTERVALS FOR THE NORTHEASTERN SITE

FIGURE C.5

DAMES & MOORE



MEAN MONTHLY TEMPERATURE AND AVERAGE OF THE MONTHLY MAXIMUM AND MINIMUM TEMPERATURES IN THE VICINITY OF THE NORTHEASTERN SITE

DAMES & MOORE

~~C-12~~ 346

FIGURE C.6

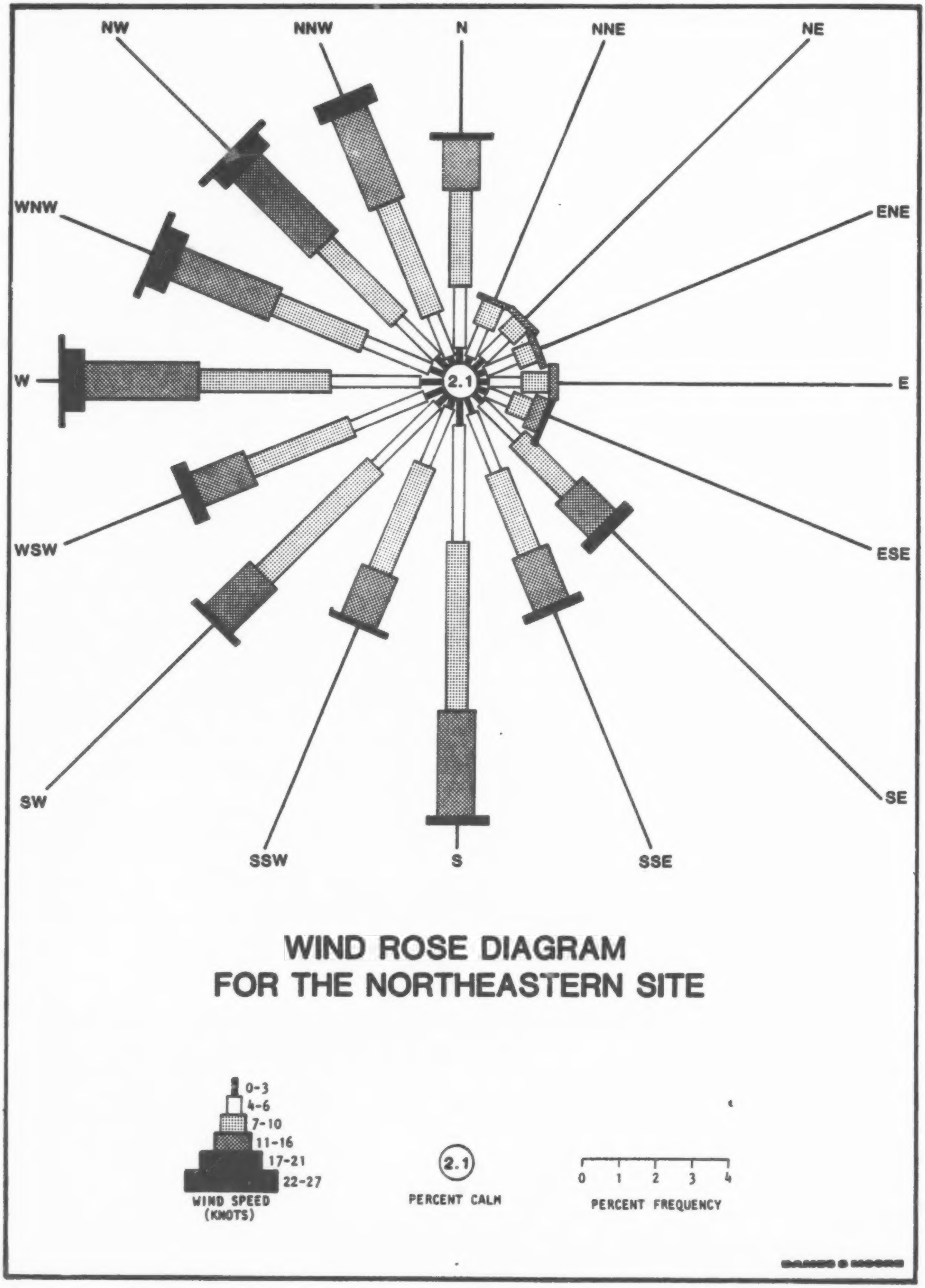
knots), respectively. The average annual windspeed near the site is 16.6 km/hr (10.3 mph), and occurs from the west-southwest direction. The wind rose diagram for the site is shown in Figure C.7.

Thunderstorms occur on an average of about 30 days per year and are more vigorous during the warm season. Tornados are not common but may occur between late May and late August. Freezing rain storms generally occur on one or more occasions during the winter but are of short duration. Since the area is characterized by frequent storm passages, particularly from late fall to early spring, relatively low frequencies of nocturnal solar radiation occur. Northwest winds blowing over the western slopes of the nearby mountains during winter also enhance the instability of the area climate. Inversions based below 152 m (500 ft) above the surface may be expected to occur 20 to 30 percent of the time in any season. As a result, mixing heights and wind speeds have less variations.

Terrestrial Ecology

The site is located within the Appalachian Highland Division of the Hemlock-White Pine-Northern Hardwoods Region. The region is characterized by pronounced alternating presence of decidious, coniferous, and mixed forest communities. Approximately half of the county in which the site is located is currently used for agriculture, with much of the remaining area covered by secondary forest growth. Public use areas within a 40 km radius of the site include the Crolia Wildlife Management Area located 2.7 km north, the Crown Lake State Park located 9.7 km south, the Frog Pond State Park located 29 km east, and the Severn Fish Hatchery located 6.4 km northwest.

The disposal facility site itself is forested. The dominant species are sugar maple, American beech, yellow birch, hemlock and white pine. The immediate vicinity of facility is also forested to a great extent, continuous with the woodlands found onsite.



WIND ROSE DIAGRAM
FOR THE NORTHEASTERN SITE

FIGURE C.7

No state or federally declared rare or endangered species are known to occur onsite. A variety of mammal species are found onsite. The most abundant are small mammals such as the white footed mouse, short-tailed shrew, woodland jumping mice, and meadow mole. Common medium sized mammals are woodchuck, opossum, and gray squirrel. White-tailed deer are also abundant in this area.

Most mammals utilizing the site, with the exception of woodchucks, are not burrowing species. These mammals dig tunnels which average 1.2 to 1.5 meters (4 to 5 ft) deep, and 7.6 to 9.2 meters (25 to 30 ft) long. Home ranges of the common mammals vary depending upon the availability of food.

A moderate number of reptiles have been observed or are expected to occur within the deciduous woodlands. Reptiles found include the eastern garter snake and the snapping turtle, the latter being essentially restricted to areas immediately adjacent to water. Other reptiles observed include the spotted salamander, the wood frog, and the American toad.

Aquatic Ecology

The aquatic environment near the site is limited to Point Creek (2 mi from the site to the east) and its tributary, Boyle Creek (1 mi from the site to the south). Point Creek leads into the Sprite River at a point 37 km (23 mi) downstream, which then drains into the Wilder River, 27 km (17 mi) further south. Both Point Creek and Boyle Creek are considered Class C waters, best suited for recreational fishing. Point Creek and its tributaries are shallow, rocky bottom streams. The major primary producers of these waters consist of several genera of diatoms, green and blue-green algae. The most common phytoplankton are Tubellaria, Fragillaria, Asterionella, and Cyclotella. The flow of these streams somewhat limits the abundance of macroflora. Forty-seven fish species are known to occur within the county in the Wilder

River watershed. Most of these species are expected in Point and Boyle Creeks. Point and Boyle Creeks are also stocked with rainbow trout, and tiger muskellunge.

Land Use

The site, which is forested, is located in a rural land area. The general region in which the site is located is comprised mostly of forested land and active or inactive farmland. There are no farm dwellings or other residences located onsite. The site is not suited for any unique uses, but the soils are considered to be suitable for farming. There is no significant mineral resource development within 10 km of the facility. County plans for the site, which is not in a visually sensitive area, and surrounding land (2 to 7 km) include reforestation and compatible uses.

There are no known mineral resources of economical consequences within the vicinity of the site. Recovery operations in the area are limited to a small bedrock quarry located one mile to the north, and a sand and gravel quarry, located one mile to the east. No oil and gas reserves of economically recoverable quantities are known to exist in the area.

Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is equal to 136. The average cation exchange capacity of the subsurface media is about 20 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 65 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 50 years. The horizontal saturated zone travel times from the edge of the vertical projection onto the saturated zone of the disposal cell closest to the discharge locations are as follows: to the restricted area fence, 150 years (30 m), to the closest drinking water well, 2,450 years (500 m), and to the nearest surface water discharge location, 5,000 years (1000 m).

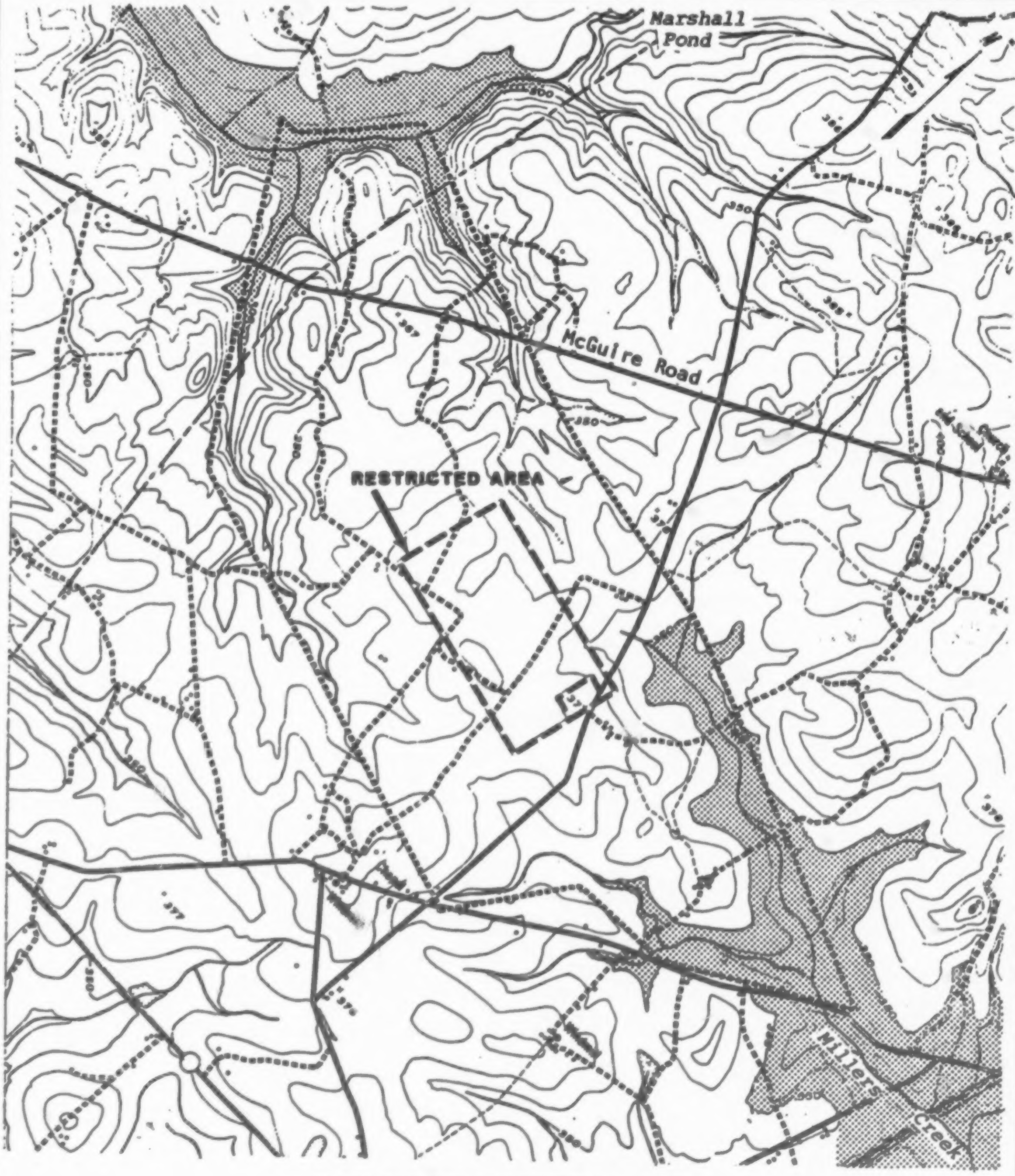
C.1.2 Southeastern Site

The southeastern site is assumed to be located within the Liptone Upland segment of the Atlantic Coastal Plain physiographic Province at elevations ranging from 120 and 122 m (394 and 400 ft) above mean sea level (msl). A general topographic map of the site is shown in Figure C.8.

The site vicinity is characterized by gently rolling hills with broad summits, and by relatively flat-lying fields bordered by somewhat broad drainage depressions. Bordering the site area to the north is the wide, flat lying topography of the Longville Plateau. In general, natural surface drainage at the site is good. As a result of the low topographic relief at the site, the probability of mass wasting and other significant erosional events is low. The local drainage system is dendritic with a typical perennial stream spacing of 1000 to 2000 m or more.

Geology

The geologic profile of the site is provided in Figure C.9. The site is underlain by 22 to 24 m of colluvium. Underlying the colluvium is a cherty limestone (Winston Road) member of the lower Stablehead Formation. The limestone has an average permeability of approximately 10^{-2} cm/sec and forms the basal portion of the unconfined aquifer. Solution features in the limestone are minor and are not of the type which would result in sinkhole development. Underlying the Stablehead are Seymour and Wrigley Clayt members of the Brittle Limb Formation. The Seymour member is a typically well-bedded, fine to coarse grained, calcareous sand with clay lithofacies occurring as beds or lenses.


Marshall Pond
McGuire Road
RESTRICTED AREA
Millers Creek

SOUTHEASTERN SITE
TOPOGRAPHIC MAP

0 500 1000
SCALE IN METERS

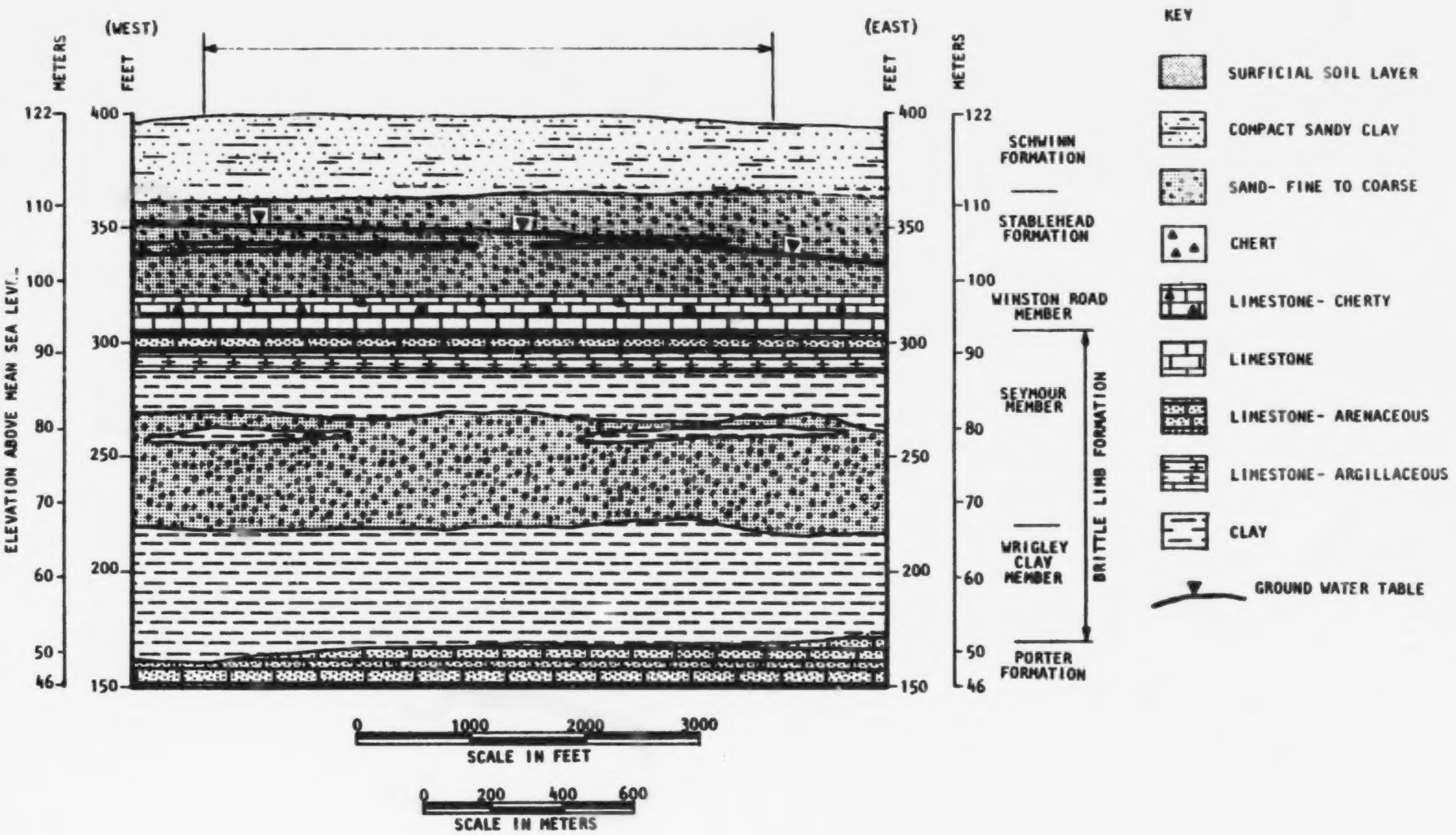
0 1000 2000
SCALE IN FEET

KEY:

▨ 500 YEAR FLOODWAY

DAMES & MOORE

FIGURE C.8


(WEST)
(EAST)
METERS
FEET
ELEVATION ABOVE MEAN SEA LEVEL
122
110
100
90
80
70
60
50
46
400
350
300
250
200
150
SCHWINN FORMATION
STABLEHEAD FORMATION
WINSTON ROAD MEMBER
SEYMOUR MEMBER
WRIGLEY CLAY MEMBER
BRITTLE LIMB FORMATION
PORTER FORMATION
KEY
SURFICIAL SOIL LAYER
COMPACT SANDY CLAY
SAND- FINE TO COARSE
CHERT
LIMESTONE- CHERTY
LIMESTONE
LIMESTONE- ARENACEOUS
LIMESTONE- ARGILLACEOUS
CLAY
GROUND WATER TABLE
0
1000
2000
3000
SCALE IN FEET
0
200
400
600
SCALE IN METERS

GEOLOGIC PROFILE OF THE SOUTHEASTERN SITE

FIGURE C.9

The uppermost portion of the Seymour in the site area consists of several thin limestone layers underlain by a clay layer. The Wrigley member consists chiefly of a calcareous, marine clay. The total thickness of the Brittle Limb Formation in the site area is about 45 meters. The clayey basal member of the Brittle Limb Formation serves as an aquiclude to deeper aquifers.

The disposal facility site is located within a general area having a peak horizontal ground acceleration of approximately 0.11 g, with a recurrence interval of more than 500 years. Structural features associated within the area are geologically old and no capable faults have been identified in the general vicinity of the site. The probability of significant ground displacement at the site is quite low.

Soils

The soils covering the reference disposal facility site are predominantly sandy loam and loamy sand. In engineering terms, these soils may be described as medium-dense silty sands and clayey sands. The surficial soils generally consist of 0 to 8 cm (0 to 3.2 in) of topsoil mixed with silty sand.

This surficial soil layer is underlain by 10 to 12 m of sandy clay from the Schwinn Formation. This sandy clay layer has an average permeability of about 5×10^{-6} cm/sec. Underlying this layer of sandy clay are unconsolidated and semiconsolidated sediments of the Eocene age Stablehead Formation. This sedimentary layer generally consists of fine to coarse sands which are locally partially cemented with occasional thin lenses of silt present. This sandy layer from the Stablehead Formation is approximately 12 to 14 m (39 to 46 ft) thick. The average permeability of this horizon is 1×10^{-4} cm/sec.

In general, under natural conditions, the nutrient levels and organic matter content of all of the soil types occurring onsite are low.

Fertilization practices may raise these levels to a more moderate level. The pH is strongly acidic with values generally ranging from 4.8 to 5.2. The cation exchange capacity of the soils will also be low due to the small clay content over most of the site, and the kaolinitic character of the minerals.

Groundwater

The depth to ground water fom the original ground surface at the site ranges from 12 to 17 m (40 to 55 ft). The aquifer is unconfined and is generally a subdued replica of the local topography. Well yields in the unconfined aquifer are typically in the range of 1-10 gallons per minute. Larger capacity uses are satisfied by deeper wells into the confined aquifer.

The groundwater quality is fair (it meets the National Primary Drinking Water Standards), however, the local consumptive use of water for potable purposes is low and consists of 6 domestic wells within 5 km (3.2 mi) and 60 wells used for farming and livestock. The closest downgradient well is located 1.4 miles from the site.

Recharge to the local groundwater system primarily results from infiltration of precipitation. The closest major withdrawal location is 36 km (22.5 mi) to the northeast where water is pumped from the lower confined aquifer for a municipal drinking water supply.

Surface Water

The nearest perennial stream to the site is Millers Creek which is located approximately 1000 m (3300 ft) to the southeast of the site (Figure C.8). This is the nearest point of groundwater discharge, at an approximate elevation of 295 ft above mean sea level. The other major stream in close proximity to the site is the Signal Branch of Basie Creek which is located approximately 2000 m (6600 ft) north of the site.

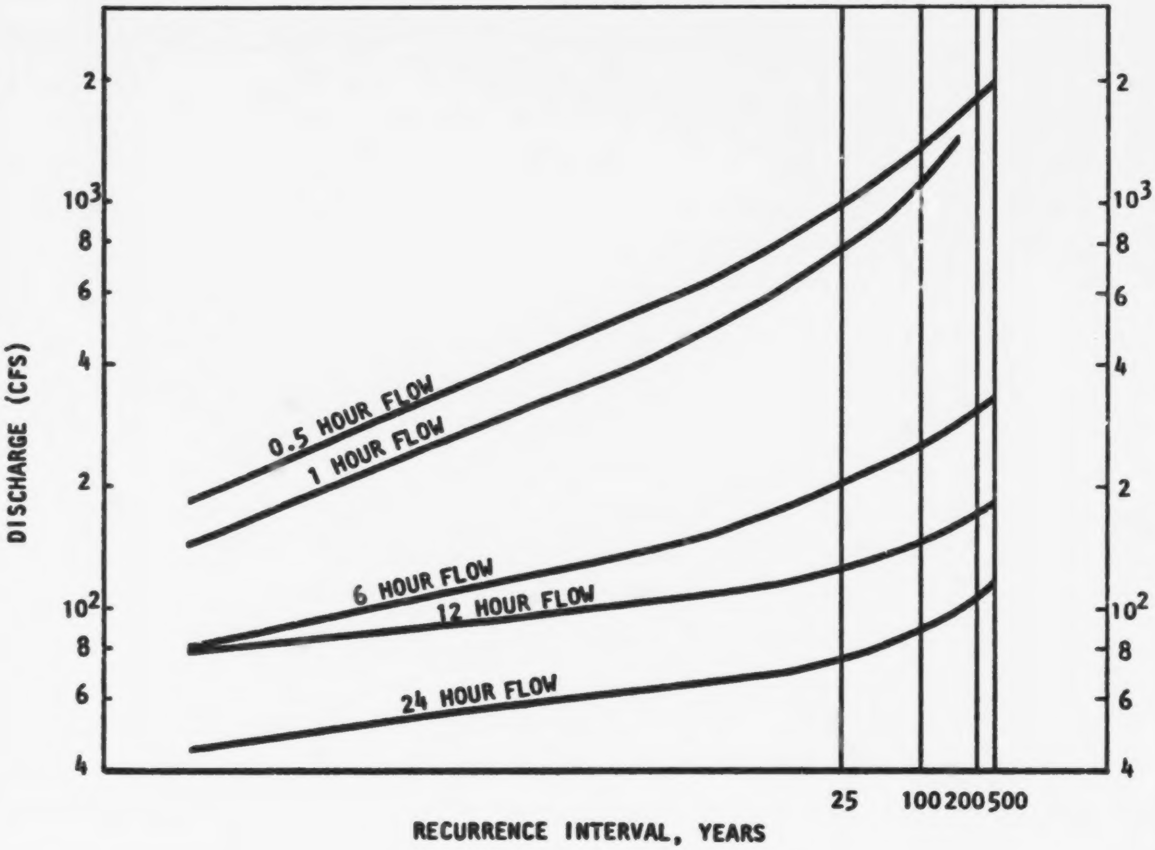
Millers Creek Discharges into the Parker River which ultimately empties into the Atlantic Ocean by Way of Feather Bay. The Signal Branch has an average discharge of 0.028 m^3/sec (1 cfs - cubic feet per second); this stream drains into the Basie Creek and the Turner River, which eventually drains into the Pepper River and ultimately into the Atlantic Ocean.

Storm recurrence analysis for storms of variable durations indicate that a 24 hour storm event with a 88.9 mm (3.5 in) total precipitation will occur once a year. The 500 year storm will yield between 96.5 and 45.7 mm (3.8 and 1.8 in) of precipitation depending on the duration of the storm. The site is located on a topographic high, and rainwater falling in the vcicinity of the site flows into one of two drainage basins: an eastern basin and a western basin. Flow recurrance intervals for the east and west drainage basins of the site are shown in Figures C.10 and C.11, respectively.

The soil, vegetation, and slope conditions on the site allow for 60 to 85 percent of precipitation to be lost by evaporation, rainsplash, surface runoff, or return flow in saturated areas. Discharge measurements from both basin outlets indicate mean average discharges of 73 cubic meters per second (26 cfs) for the eastern basin and 2.1 cubic meters per second (74 cfs) for the western drainage area. Due to the limited extent of the basins, a direct corrollary between precipitation intensity and peak stream flow exists. Peak runoff for the eastern basin is expected to occur between 55 and 68 minutes after precipitation begins; and for the western basin, between 150 and 172 minutes. The extent of the projected 500 year flood is shown in Figure C-8.

Meteorology

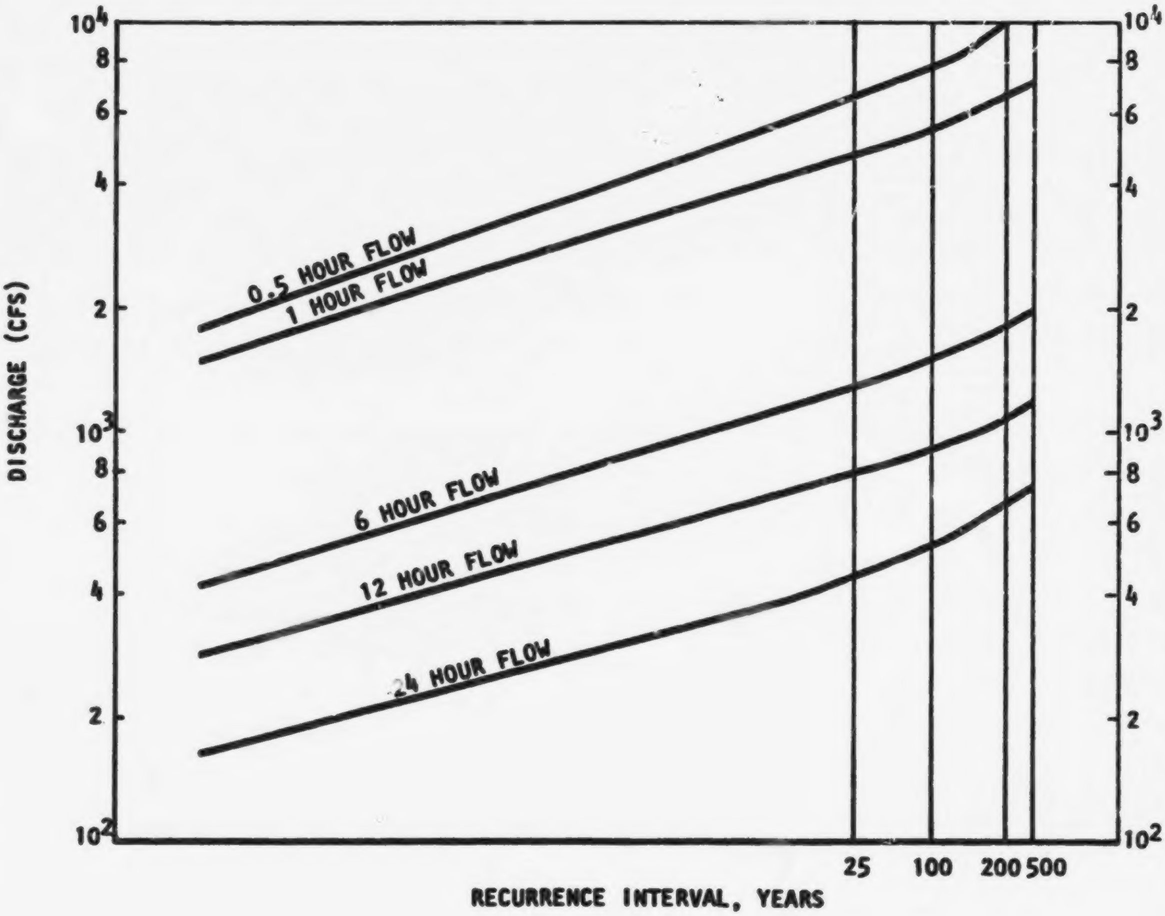
The area of the site is classified as a humid subtropical climatic regime. The annual precipitation at the site over the past twenty



FLOW RECURRENCE INTERVALS FOR
EAST BASIN OF THE
SOUTHEASTERN SITE

DAMES & MOORE

FIGURE C.10



FLOW RECURRENCE INTERVALS FOR WEST BASIN OF THE SOUTHEASTERN SITE

DAMES & MOORE

FIGURE C.11

years has been 1168 mm (46 in), with an annual range of 838 to 1473 mm (33 to 58 in).

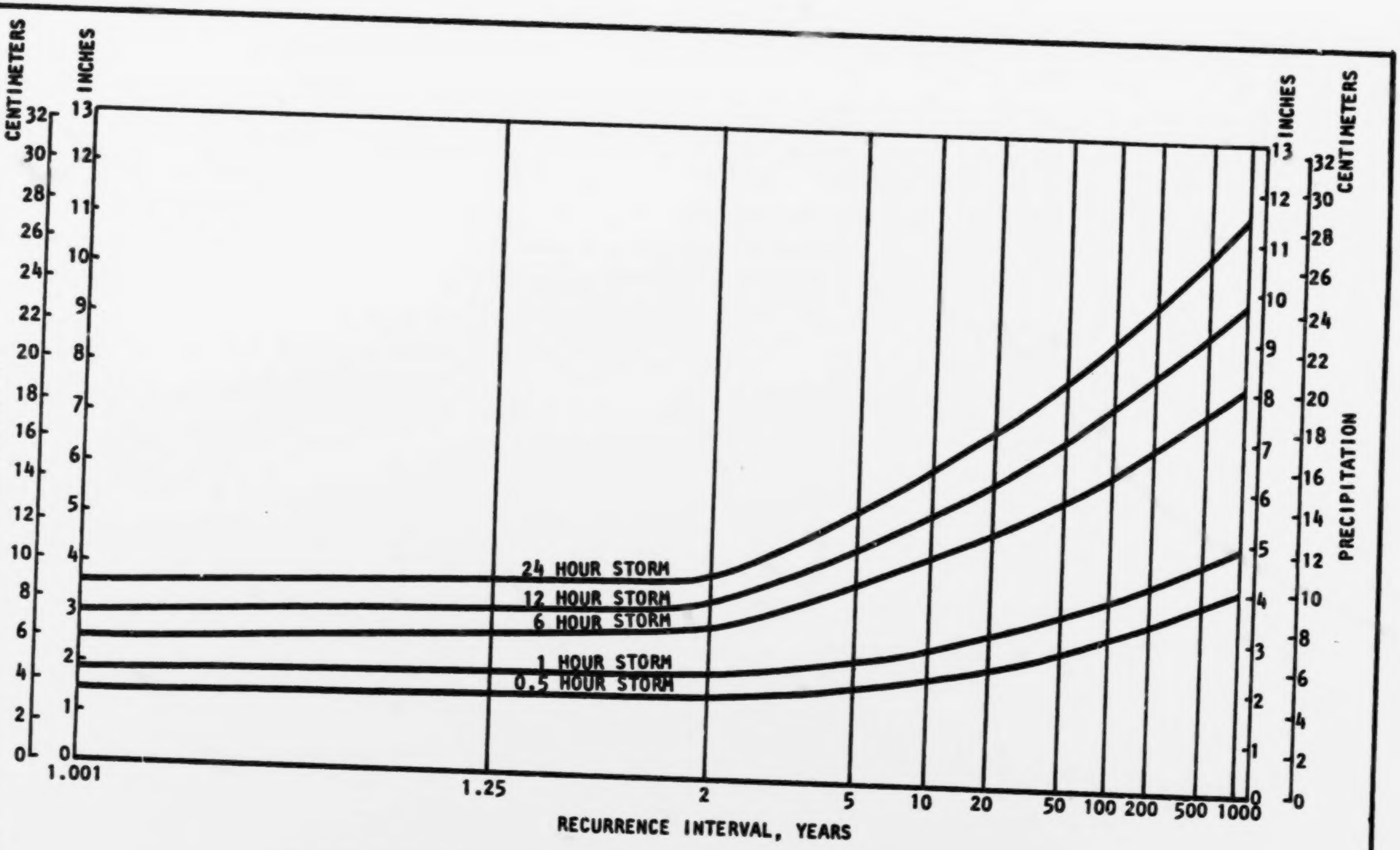
High intensity storms can result from the remnants of inland travel of hurricanes and tropical storms. The maximum 24-hour rainfall recorded at the site over the last twenty years is 152 mm (6 in). Snowfall is generally observed during the months of January and February. Precipitation event recurrance intervals for the site are shown in Figure C.12.

The site area experiences four distinct seasons. Winters are short and relatively mild with average temperatures of 9°C (49°F). Summers are characteristically warm, averaging 24°C (76°F) and 27°C (80°F), while the spring and fall periods are relatively mild. The average annual temperature for the site area vicinity is 18°C (65°F), with the maximum occuring in July and August. The relatively mild temperature variation observed at the site suggests that large-scale desiccation and frost heaving of trench caps are not likely to occur. The temperature characteristics of the site are shown in Figure C.13.

The prevailing wind direction is south-southeasterly at an average windspeed of 13 km/hr (7.0 knots). The wind rose diagram for the site is presented in Figure C.14. The average humidity at the site is 78% with an average low of 68% usually occurring in January and an average high of 88% usually occurring in August.

Tornado activity within the immediate area of the site proper is moderate with an estimated occurrance of one tornado every 500 years. Within 50 km (31 mi) of the site, the occurrance frequency of tornadoes is on the order of once every fifty years.

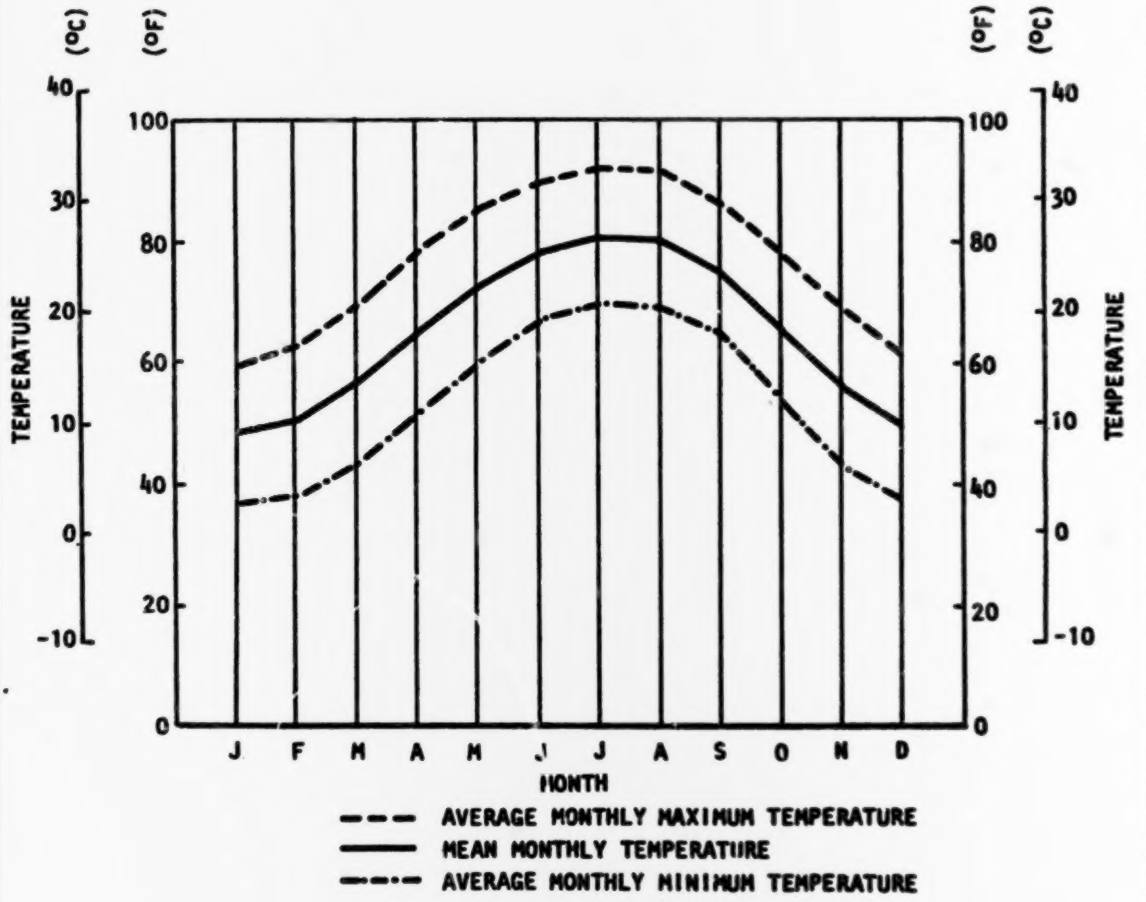
The air quality at the site is quite good with concentrations of all major pollutants below USEPA standards. The good air quality is largely due to a lack of point sources of pollution near the site.



PRECIPITATION EVENT RECURRENCE INTERVALS FOR THE SOUTHEASTERN SITE

FIGURE C.12

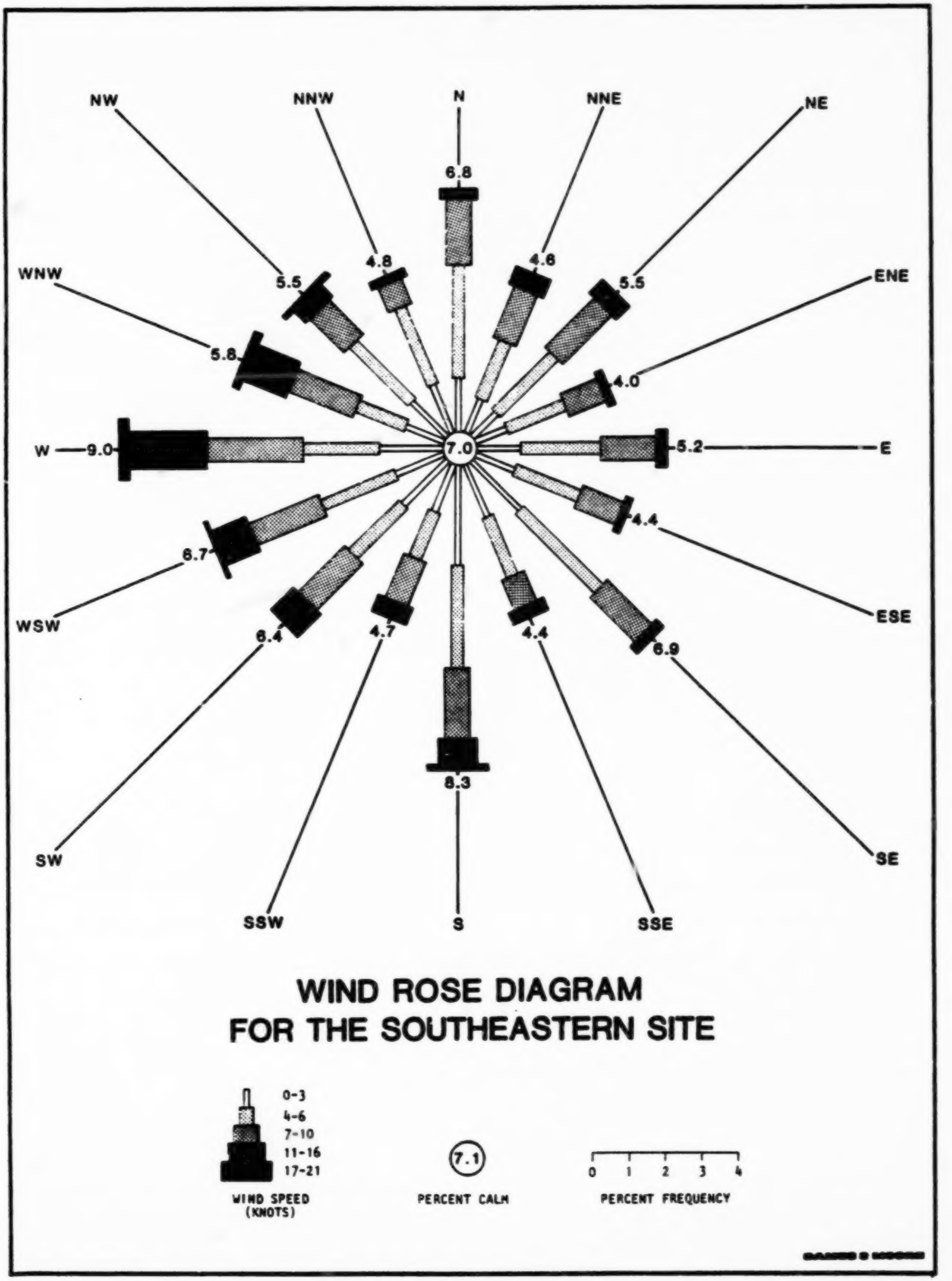
DAMES & MOORE



MEAN MONTHLY TEMPERATURE AND AVERAGE OF THE MONTHLY MAXIMUM AND MINIMUM TEMPERATURES IN THE VICINITY OF THE SOUTHEASTERN SITE

DAMES & MOORE

FIGURE C.13



WIND ROSE DIAGRAM FOR THE SOUTHEASTERN SITE

FIGURE C.14

The only major point source of airborne pollutants is a coal fired electrical generating station located 43 km (27 mi) to the northeast of the site. Farming activity on land adjacent to the site is also a source of air pollutants. Air quality at the reference disposal facility is summarized below.

Pollutant	Concentration (mg/m^3)	USEPA Standard
Suspended particulates		
24-hour average	90	150
annual average	45	60
SO_2 (annual average)	20	60
NO_x (annual average)	28	100
Hydrocarbons		
3-hour average	70	160
annual average	68	--

Terrestrial Ecology

Much of the general area of the site is composed of undeveloped woodland which is dominated by longleaf pine and turkey oak. The herbaceous layer is mostly turkey oak saplings, but bluejack, post oak, and longleaf pine are also important. In addition to the pine-upland hardwoods found near the site, there are two other forest communities: bottomland hardwoods bording the eastern portion of the site along Signal Branch and bluff hardwoods along the steeper slopes of Millers Creek. Water oak, black (or sour) gum, and tupelo gum are the dominant overstory species in the bottomlands. The bluff hardwoods are characterized by hickory and northern red oak. Water oak, northern red oak, ash and mulberry are the understory species.

Nestronia, a deciduous shrub that is considered to be threatened in the state, is expected to occur in the pine-upland hardwoods. It also may be found in the transition zone between these woods and the may be found in the transition zone between these woods and the bottomlands found closer to Signal Branch. While the bald eagle and red-cockaded woodpecker may also be found in the county in which the site is located, they are not expected onsite or within 5 km of the site due to lack of suitable habitat. No other federally or state protected species are anticipated to inhabit the area.

The most common mammals found in the pine communities are pine mouse, fox squirrel, and raccoon. Burrowing species that were observed are southeastern pocket gopher and eastern mole. Gopher tunnels are generally over 30 meters (100 ft) in length and dug at a depth of 15 to 20 cm (6 to 8 in). While tunnels leading to the resting chambers of the eastern mole may be 14 cm deep, most are only 2.5 to 5 cm (1 to 2 in) deep, and may extend for over 0.8 km.

Other mammals associated with the hardwood communities of the area include the raccoon, opossum, woodrat, flying squirrel, gray squirrel and swamp rabbit. Bobcat and gray fox have also been observed. Common mammals found in the old field communities, and also in the cultivated fields are several species of mice and, cottontail rabbit, least shrew striped skunk, raccoon and opossum. Most mammals found in this area are not underground burrowers.

Home ranges of most of the mammals found in the general area of the site are relatively small: striped skunk - 4 ha (10 a); fox squirrel - 4 to 16 ha (10 to 40 a); gray squirrel - .8 and 2.8 ha (2 to 7 a); eastern cottontail - 3 to 20 acres. Bobcat have the largest range, the size of which is influenced by the abundance of prey. Their general range is 8 km (5 mi), however they may wander up to 40 km (25 mi). The gray fox may also wander over a large area particularly during the winter.

As with the mammals, the different vegetative communities provide habitat for several varieties of birds. Common species of the pine communities include the state-colored junco, brown-headed nuthatch, pine warbler, bluejay and common crow. The golden crowned-knight, common flicker, and pileated woodpecker are common in the hardwood forests. Predatory birds such as red-shouldered hawk, red-tailed hawk, coopers hawk and barred owl are also found in moderate numbers in these latter woodlands. These birds feed on the rodents and other terrestrial vertebrates found in the area. The open fields and edge communities provide habitat for the eastern meadowlark, field sparrow, mockingbird, robin and common grackle. Dominant raptors in these areas are the marsh hawk and sparrow hawk. The fields also provide hunting areas for the other hawks mentioned.

The pine upland forests provide habitat for many snakes, including the corn snake, northern pine snake, black racer and diamondback rattlesnake. The burrow of a gopher tortoise was also observed 4.5 m (15 ft) from the northwestern boundary of the site. The gopher tortoise is an accomplished burrower, its tunnels may be as wide as 33 cm, and generally as long as 10 meters. Many other animals temporarily or permanently use these burrows, including numerous insects, opossum, and diamondback rattlesnakes. The more common reptiles of the moister hardwood communities are the dusky salamander, cricket frog, brown snake and eastern box turtle.

Active farming in the vicinity of the site limits the diversity and abundance of the resident reptiles in these areas. Species that were commonly found in the old field communities that may wander into the cultivated fields include the southern toad, six lined racerunner and eastern hognose snake. This latter species is known to burrow in search of food.

In general (with the exception of the upland pine areas), the biomass of southeastern forests and fields is high, compared to many other regions in the United States. Mild climate and sufficient rainfall promotes rich, stratified vegetative growth, which provides suitable habitat and abundant food source for many herbivores and omnivores. Primary and upper level carnivores, in turn, rely on the abundance of these species.

Aquatic Ecology

Primary producers of the two nearby creeks include both algae and macrophytes (aquatic vascular plants). Periphyton (attached algae) are more common in the flowing waters of these streams; however, increased turbidity or organic loading can quickly reduce the abundance and types of algae found. Eight genera of aquatic plants were identifiued within the nearby creek waters. These plants are most abundant in areas of reduced current flow. The plants found, in descending order of abundance, are:

Common Name	Scientific Name	Relative Abundance
Water milfoil	Myriophyllum sp.	Most abundant
Hornwort	Ceratophyllum sp.	Most abundant
Alligator weed	Alternanters sp.	Very abundant
Water weed	Anacharis sp.	Abundant
Duck potato	Sagittaria sp.	Not Abundant
Pickerel weed	Pontederia sp.	Scarce
Cattail	Typha sp.	Scarce

No endangered of threatened plant species are expected to occur. A significant diversity of invertebrate species are also found in these waters. The three most abundant groups, comprising just over 75 percent of the total number of insects sampled, are mayflies, beetles, and waterfleas.

Approximately 38 species of fish are known to occur in the surface water system. The most abundant fish are shinners, minnows, sunfish and darter. Common recreational species include largemouth bass, pickerel, channel catfish, black crappie, and sunfish. Two nearby ponds are more popular fishing areas, however, than Millers Creek and Signal Branch. Although several andromous species do spawn in the rivers, no major spawning activity is noted in the above creeks. No protected fish species have been recorded for these waters.

Land Use

Within an 80 km (50 mi) radius of the site, there are three principal categories of land use: (1) woodland (about 25% of the area) with both private and government preserves, (2) farmland (about 55% of the area) with an approximate 50:50 mixture of rowcrops and pasture, and (3) developed land (about 20% of the area) occupied by light industry and residential dwellings. The area ocupied by the site had been used for farming in the past, however, for the last several years the land has been uncultivated and a thick secondary growth has grown up.

The site vicinity and surrounding region is primarily agricultural, with little high intensity development located outside of the towns and cities. A school is located 6.4 km (4 mi) northwest of the site. There are no historic sites, community facilities (other than the school), or sensitive land uses located within 8-10 km of the site, and the site is not particularly suited for unique uses. In the absence of any indications of any incentives to develop the areas near the site for non-agricultural uses, it is assumed that agriculture will remain the dominant land use.

Mineral resources of a recoverable nature underlying the site are limited to sand and gravel deposits. While these sands are not believed to be pure enough for glass making, they are suitable for use as fill or construction purposes. These deposits are widespread over much of the southeastern portion of the state, and as such, do not constitute a unique resource.

Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is equal to 91. The average cation exchange capacity of the subsurface media is about 10 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 50 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 10 years. The horizontal saturated zone travel times from the edge of the vertical projection onto saturated zone of the disposal cell closest to the discharge locations are as follows: to the restricted area fence, 32 years (30 m), to the closest drinking water well, 400 years (500 m), and to the nearest surface water discharge location, 800 years (1000 m).

C.1.3 Midwestern Site

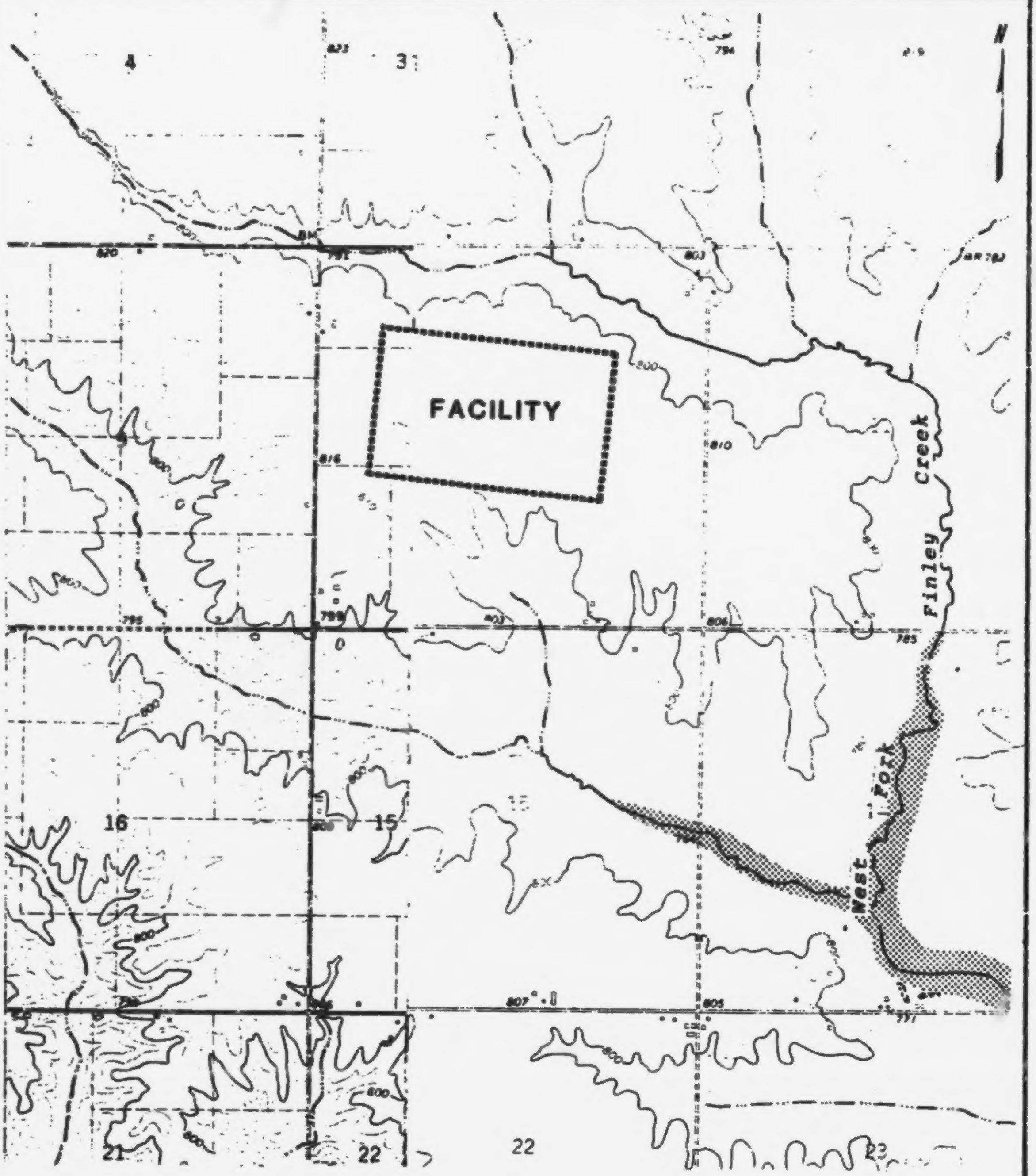
Falling within the Central physiographic province, the midwestern site rests at an average elevation of about 247 m (810 ft) above mean sea level (msl). The general topography of the site, which is shown in Figure C.15, is that of a well dissected plain which is virtually encircled by various branches of the West Fork of Finley Creek. The regional topographic surface undergoes only small changes in relief.

Geology

A considerable thickness (about 35 m or 115 ft) of unconsolidated deposits underlies the site. Most of this is composed of a rather impermeable glacial till consisting predominantly of pebbly and sandy clay and silt, and gumbotil. Gumbotil is a clay-rich till produced as a result of thorough chemical decomposition. Portions of the glacial drift may contain sand and gravel pockets of limited areal extent.

Southeast of the site is an area underlain by buried channel deposits reflective of an ancient stream channel. This channel consists of stream alluvium that filled the valley prior to or between glacial periods. The buried channel represents the upper reaches of a tributary to what is presently called the Washoe Channel. Evidence of this system is the increased depth to bedrock by about 23 m (75 ft).

The bedrock consists of approximately 30.5 m (100 ft) of Mississippian age rocks belonging to the Dette and Adams Series. The uppermost formation of the Dette series, the Pile shale, which generally acts as an aquiclude to the underlying Karesh and Becker formations, is absent from the site area. The Karesh limestone is thin and discontinuous over the Becker. Both formations are chiefly dense, crystalline, lithographic or tightly cemented fragmental limestones and dolomites with very low porosities. The basal 3 m (10 ft) of the Becker consists of cherty sandstone.


N
4
31
823
794
820
BM
791
803
800
FACILITY
816
810
Finley Creek
799
795
803
806
785
West Fork
16
15
807
805
791
21
22
22
23

MIDWESTERN SITE
TOPOGRAPHIC MAP

0 500 1000
SCALE IN METERS

KEY:

▨ 500 YEAR FLOODWAY

DAMES & MOORE

FIGURE C.15

Underlying the Dette series are the dense, cherty dolomites and limestones of the Adams series. These rocks are exposed at the buried channel/bedrock contact point. These two series make up what is known as the Mississippian Aquifer. They are underlain by approximately 400 feet of siltstones and shales of Devonian age that serve as a good aquiclude to the underlying Devonian Aquifer. Stratigraphic sequences and the location of the groundwater table are illustrated in the geologic profile on Figure C.16.

The midwestern site is located within the tectonically stable interior of the North American continent. The closest area of major seismic risk covers the eastern section of the adjoining state to the north. The site area has a probable peak horizontal ground acceleration of less than 0.04 g, with a recurrence interval of more than 500 years. Within historical record, no evidence was found to indicate the occurrence of a capable fault within the site area.

Soils

The entire area in which the site is located is covered by about 3 to 3.7 m (10 to 12 ft) of Wisconsin loess, which is the parent material of the site soils. The predominant soil types are silty clay loams belonging to the Wancho, Houlik and Lyle series. These soils are generally moderately-slow to moderately-well drained and have permeabilities ranging between 5 and 50 mm/hr (0.2 to 2.0 in/hr). The soil is generally highly acidic in the topsoil layer and slightly acidic to neutral in the substratum. Organic matter content is consistently high throughout the series. Available nitrogen and phosphorus are low to medium, and the soil content of potassium and calcium is very low.

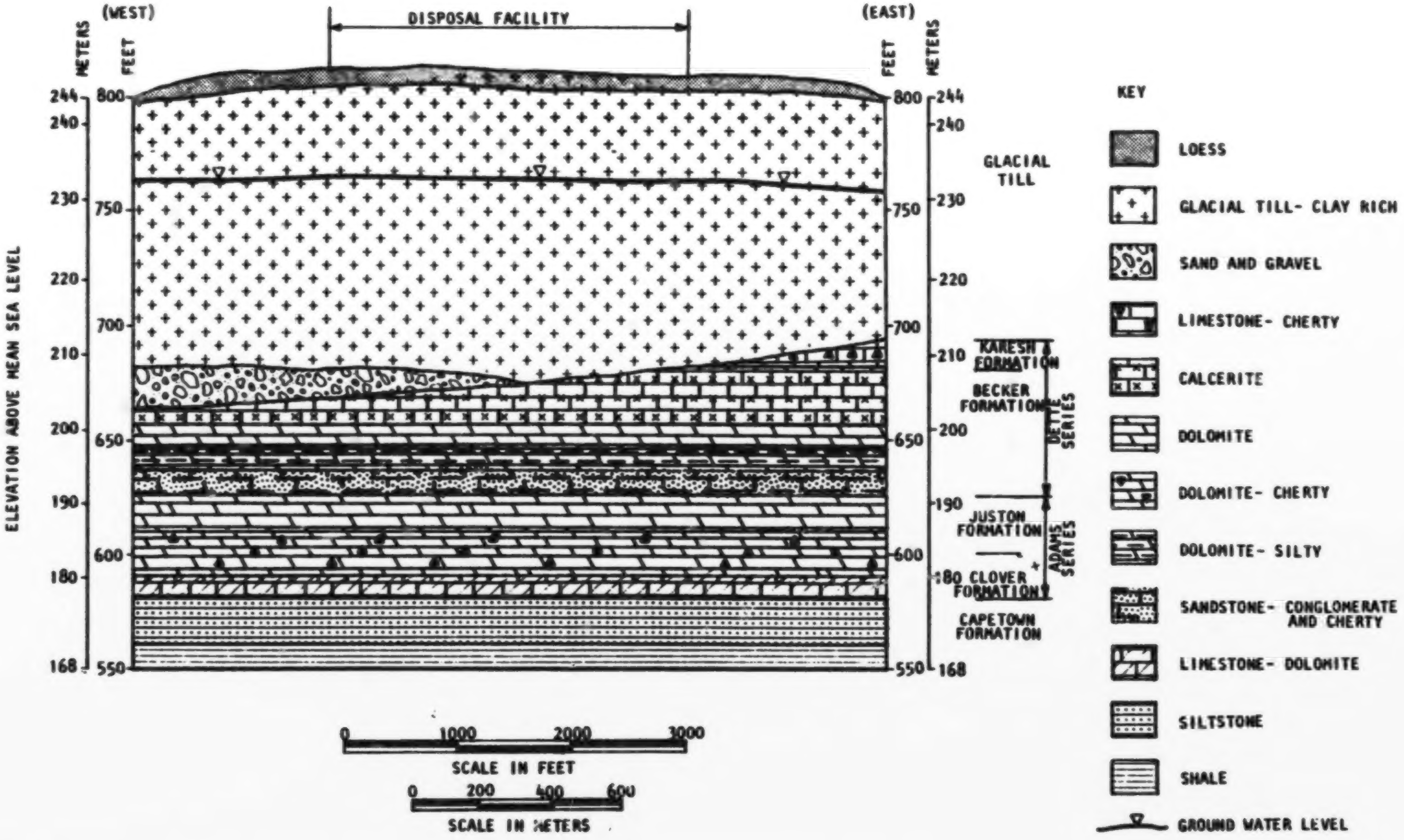
Ground Water

Ground water of appreciable amounts occur chiefly in the sand and gravel deposits associated with the glacial drift and buried channel systems. These "drift aquifers" are notably limited in areal extent, although they sometimes serve as sources for farmsteads and livestock drinking water. Water quality from the drift aquifers is generally good, being low in dissolved solids and mineral constituents, however, nitrates in excessive amounts are common, especially in those deposits close to heavily fertilized ground surfaces.

Thicknesses of about 15 m (50 ft) or more of sand and gravel have been associated with some of the larger buried valley systems. As the channel in the site proximity is more representative of the upper limits of a tributary to such a valley, it is likely to have lesser quantities of permeable sediments. Water from these deposits is more highly mineralized than in the drift aquifers. Permeabilities on the order of 0.048 to 0.48 cm/sec (1,000 to 10,000 gpd/ft^2) can be expected depending upon how well sorted the sand and gravel deposits are within these aquifers.

Water in these Mississippian rocks is generally confined to secondary openings, and movement is considered to be very slow. Specific capacities are estimated to be less than 1.0 gallon per minute per foot of drawdown. Based upon the dense, impervious nature of the rock, a permeability of 2.4x10^{-5} cm/sec (0.5 gal/day/ft^2) can be assumed. With little exception, water from the Mississippian aquifer in the site area offers good to fair quality water.

The depth to the seasonally high ground water table under the site is expected to be about 12 m (38 ft) from the ground surface. Local ground water movement in the drift aquifer will be governed by the topography, draining toward and being discharged into the various branches of the West Fork of Finley Creek. Ground water from the surficial aquifer, and also from the shallow bedrock aquifer, can be expected to discharge to the buried alluvial deposits. The regional ground water flow in the Mississippian aquifer is to the south-southeast as controlled by the nearest major stream, the Deer River.


(WEST)
DISPOSAL FACILITY
(EAST)
METERS
FEET
FEET
METERS
244
240
230
220
210
200
190
180
168
800
750
700
650
600
550
ELEVATION ABOVE MEAN SEA LEVEL
GLACIAL TILL
KARESH FORMATION
BECKER FORMATION
DETTE SERIES
JUSTON FORMATION
CLOVER FORMATION
ADAMS SERIES
CAPETOWN FORMATION
0
1000
2000
3000
SCALE IN FEET
0
200
400
600
SCALE IN METERS
KEY
LOESS
GLACIAL TILL- CLAY RICH
SAND AND GRAVEL
LIMESTONE- CHERTY
CALCERITE
DOLOMITE
DOLOMITE- CHERTY
DOLOMITE- SILTY
SANDSTONE- CONGLOMERATE AND CHERTY
LIMESTONE- DOLOMITE
SILTSTONE
SHALE
GROUND WATER LEVEL

GEOLOGIC PROFILE OF THE MIDWESTERN SITE

FIGURE C.16

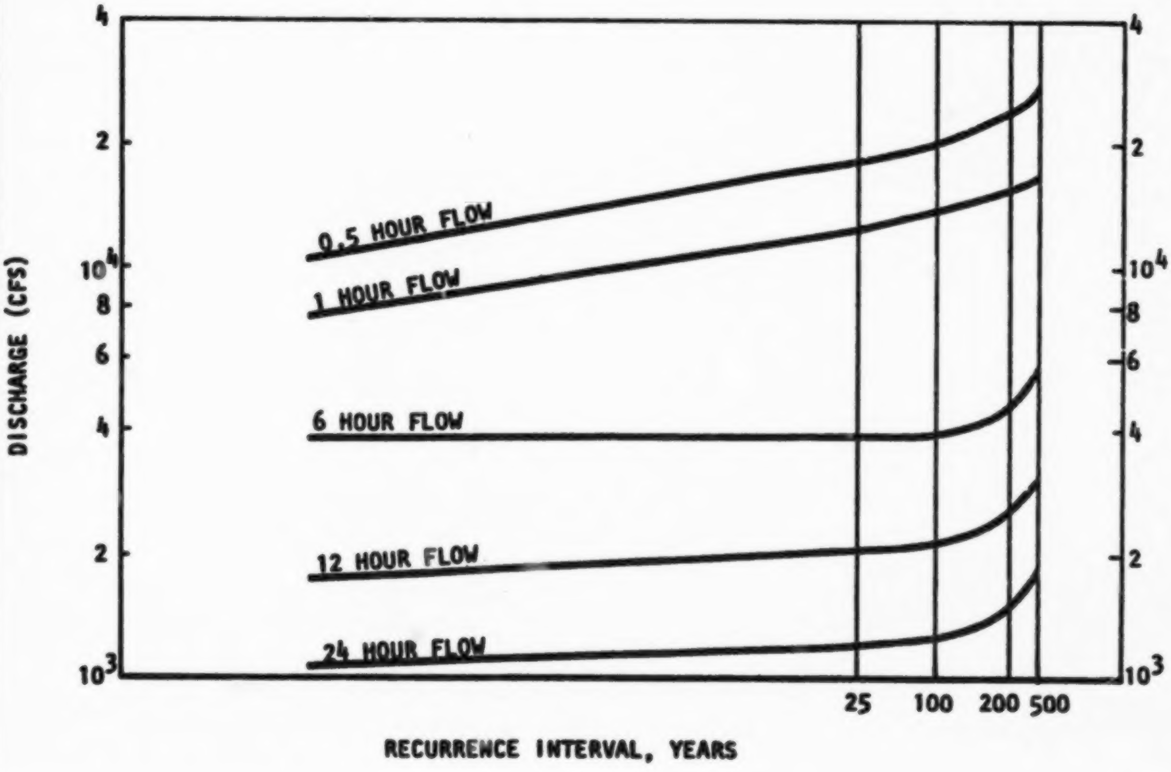
Ground water usage in the area is limited to consumption as needed by local homes and farmsteads for domestic, irrigation and livestock supplies. It is estimated that the majority of wells tap Mississipian aquifers and to a lesser degree, the drift aquifers. Yields of less than 76 lpm (20 gpm) are the rule for this area. The only municipal supply in proximity to the site belongs to the town of Mica, located about 5.6 km (3.5 mi) to the southeast. Four of the nine municipal wells tap the Lower Mississippian Aquifer. The remaining wells utilize the Lower Ordovician Aquifer.

Surface Water

The site is located on a section of the Great Plains that is undergoing dissection as a result of recent climatic change. Approximately 90% of the streams in the drainage area are intermittent, flowing only 6 to 8 months of the year. The drainage density of the basin is 0.64, indicating a coarse drainage texture which is typical of this region. Flow rates from the site average between 0.74 to 0.99 m^3/s (26 and 35 cfs) for the year.

Since the site is of limited areal extent, the correlation between precipitation and stream discharge is very close. Peak discharge rates are related to precipitation events of high intensity. Between 60 and 80 percent of precipitation in the drainage basin is discharged as surface runoff. Analysis of the unit hydrograph of the site area indicates that peak flow usually develops between 6 and 7 hours after precipitation begins. Base flow and return flow play important roles in the basin drainage; the extent is determined by the intensity and duration of the precipitation event. Flow recurrance intervals for the midwestern site area are shown in Figure C.17.

As expected, the highest stream discharge rates are associated with rain storms of limited duration but with high intensity (ranging between 102 and 152 mm/hr). The 500 year flow floodway is delineated in Figure C.15.



FLOW RECURRENCE INTERVALS FOR THE MIDWESTERN SITE

DAMES & MOORE

FIGURE C.17

During the development of the site the discharge rate is expected to increase as the area is cleared of vegetation, and due to impervious covers which may be placed over the disposal cells. While the site development will decrease the time to peak discharge and increase the peak flood stage, there will be no significant risk of flooding at the site due to the elevation differences between the area and the site outflow. While overland flow of considerable velocity may be expected during site development, prudent drainage engineering will be able to divert flow, reduce velocities and limit erosion of the site.

Meteorology

The area has a humid continental climate, with a total annual local precipitation of 777 mm (30.5 in). Approximately two-thirds of the annual precipitation occurs during the months of April through September. The source of this precipitation is the warm moist southerly air from the Gulf of Mexico. The normal mean snowfall for the site area is approximately 686 mm (27 in). Precipitation recurrance intervals for the site area are shown in Figure C.18.

The average annual temperature in the site vicinity is approximately 11°C (51°F). July is the hottest month, having an average daily maximum of 31°C (87°F) and an average daily minimum of 18°C (64°F). During January, the coldest month, the daily temperature range is approximately -0.6°C (31°F) to -11°C (12°F).

The prevailing wind direction at the site is southerly at an average speed of 17 km/hr (9.0 knots). During the months of November through March, a northwesterly wind component develops in response to the Canadian cold air outbreaks. Wind speeds during these months average 22 km/hr (12.1 knots). Severe weather events such as thunderstorms and tornadoes occur during midspring to late summer. The wind rose diagram for the site vicinity is shown in Figure C.19.

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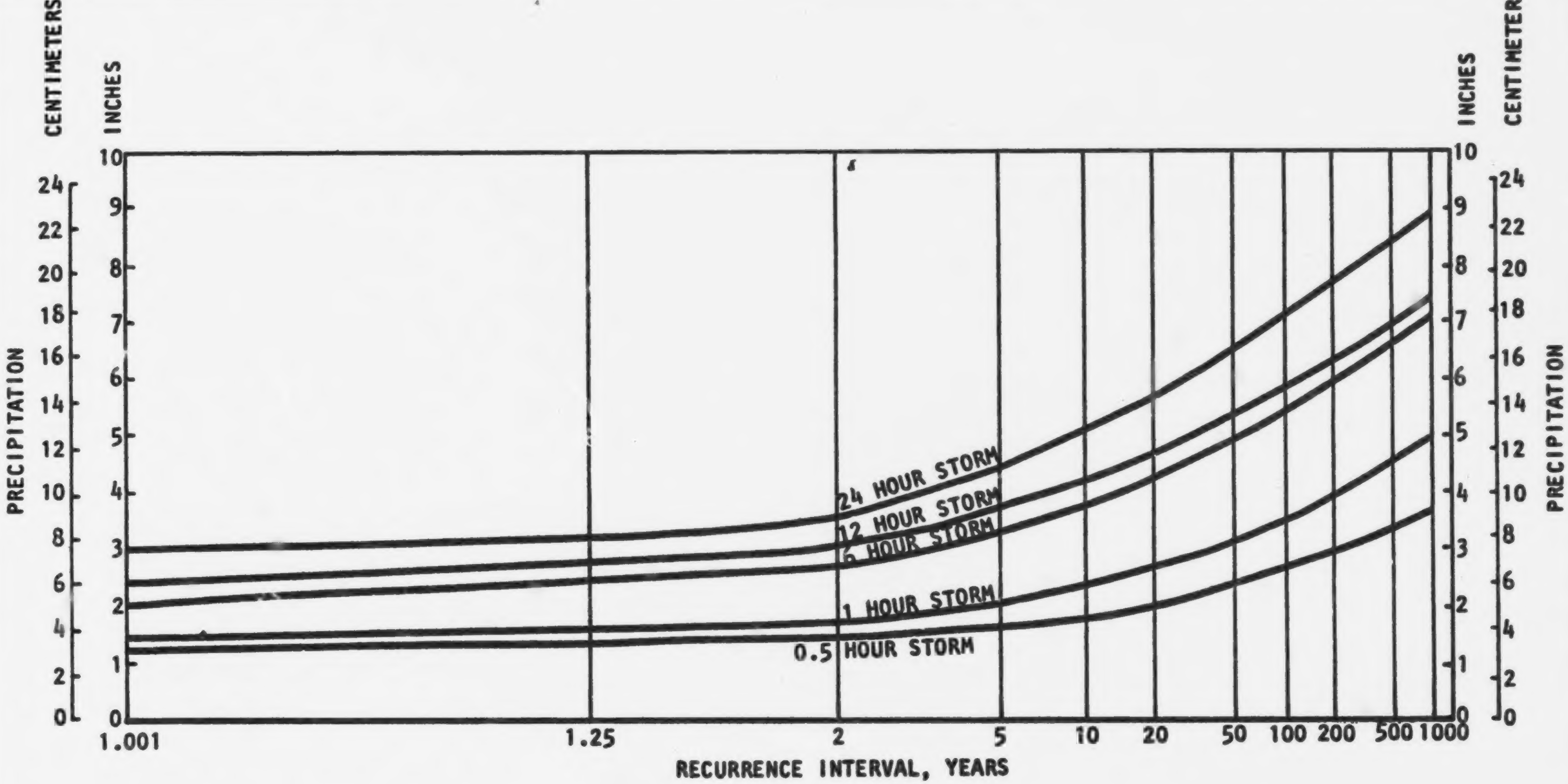
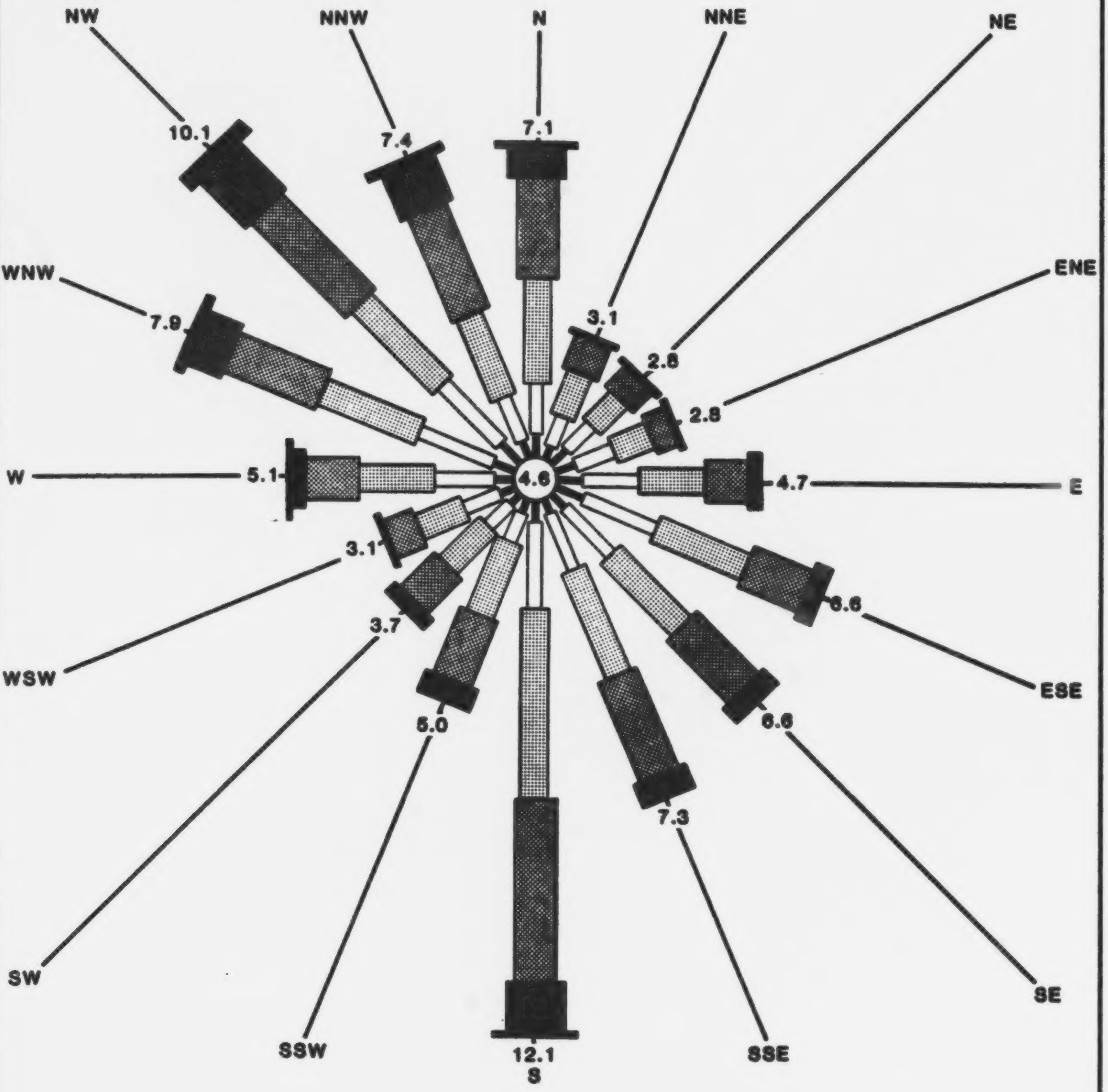


PRECIPITATION EVENT RECURRENCE INTERVALS FOR THE MIDWESTERN SITE

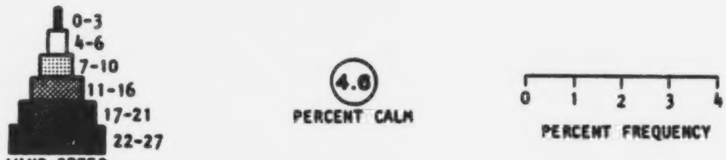
FIGURE C.18

DAMES & MOORE

C-43



WIND ROSE DIAGRAM
FOR THE MIDWESTERN SITE



0-3
4-6
7-10
11-16
17-21
22-27
WIND SPEED
(KNOTS)
4.6
PERCENT CALM
0
1
2
3
4
PERCENT FREQUENCY

FIGURE C.19

Statewide occurrences of tornadoes average about 10 for any given 8 year period. From the period 1920 to 1960, there have been approximately 75 occurrences within 2° latitude/longitude square inclusive of the site.

Since the site has a pronounced continental type of climate, it has inversion frequencies closely related to the diurnal cycle. In general, inversions occur 20 to 30% of the time during spring and summer, while during the fall and winter months, inversions may be expected about 30 to 45% of the time. The higher frequency during the fall and winter is probably a result of the relatively low number of storms in the fall and maximum length of stable nocturnal period in winter. The opposite is true for the summer months. As a result, annual morning and afternoon mixing heights vary by small amounts.

Terrestrial Ecology

The natural vegetation within the vicinity of the site is a mixture of oak-hickory forest and bluestem prairie. The forest community occurs primarily along valley slopes and upland ridges. Big bluestem is the dominant grassland plant where the prairie remains. However, most of this area is cropland. Two terrestrially environmentally sensitive areas, Deer River Access and Chatham Timbers, are located 18 km (11 mi) to the southwest and 38 km (24 mi) to the south, respectively. Green Lake, which is a prime recreational fishing area, is located 21 km (13 mi) southeast.

The two major land uses of the county in which the site is located are pastureland (24 percent) and row crops (65 percent), with corn and soybeans representing the dominant crops. Approximately 35 and 12 percent of the county, respectively, are planted in these crops. Most of the naturally occurring prairie has been lost in the county. Existing grasslands, dominated by introduced species, are interspersed in 60 to 80 ha (150 to 200 acre) blocks throughout the county.

Almost 60 percent of the land area adjacent to the site is planted in corn. Four small woodlots, about 4 ha (10 a) total, are found in the near vicinity of the site -- either adjacent to residences or farm buildings, or along creek boundaries. White oak, red oak, and shagbark hickory dominate these woodlands. Small blocks of grassy areas occur along stream banks, roadsides and other areas. Common introduced grasses include bluegrass and smooth brome. Similar ground cover is found within an 8 km radius of the site, with slightly more oak-hickory forests occurring along the Deer River system.

No Federally declared endangered or threatened species have been observed on or near the site. The most common mammals found onsite and within a five mile radius are those for which corn is a predominant food source, and can live in proximity to man. The most abundant species include the raccoon, striped skunk, eastern cottontail, opossum and fox squirrel. Several burrowing mammals are also found in the area, primarily in fields not actively cultivated. These burrowing mammals include the badger, plains pocket gopher and thirteen-lined ground squirrel. The badger and pocket gopher dig tunnels in search of food which can be 1.2 to 1.5 m (4 to 5 ft) in depth and up to one hundred meters long.

Most of the mammals that utilize the site have small home ranges, e.g., thirteen-lined ground squirrel - 0.8 to 1.21 ha (2 to 3 a), eastern cottontail - 3 to 8 ha (20 acres), and opossum - 6 to 16 ha (15 to 40 acres). The raccoon, with a maximum range of 3.2 km (2 mi), and an average of 1.6 km (1 mi), has the largest home range of those species expected in this area.

Corn very often is a major winter food source for many upland gamebirds, including birds found in the area. The ring-necked pheasant and bobwhite quail are the species most commonly hunted. Black ducks, mallards and pintails are also numerous in the area, and feed heavily on corn.

Numerous resident bird species are also found onsite and in the surrounding cornfields. The most common species found, and which feed extensively on corn, include the redwing, cardinal, meadowlark, purple grackle, and common crow. Resident birds of prey include the red-tailed hawk and great horned owl. Transient species include the coopers hawk, broad winged hawk, and red-shouldered hawk.

As a result of ongoing agricultural activities, the reptile and amphibian population of the area is limited. An occassional eastern plains garter snake, bullsnake, or black rat snake may be found.

Aquatic Ecology

With the exception of the northwestern border, the site is surrounded on all sides by the West Fork of Finley Creek, and other unnamed intermittant tributaries. Finley Creek feeds into the Deer River approximately 51 km (32 mi) downstream. There are no Federally declared wild or scenic rivers within five miles of the site.

The West Fork of Finley Creek and its tributaries are Class B warm waters. Primary uses of the creek are for wildlife, fish, aquatic and semiaquatic life, and secondary contact water uses. Although the soils along the stream banks are moderately to highly erodable, the vegetated banks limit the amount of sediments that enter the streams. No Federally declared endangered or threatened fish or snails are expected in these streams.

Land Use

The site is located on agricultural land used extensively (85 percent) for cultivation of crops, mostly corn. Five houses are located within 5 km of the site. The site vicinity contains 4 towns - Mica, Grendle, Reed and Lyme - but most of the land is not developed intensively. Hayer Park (10 acres) is located 4.8 km from the site. There are no other community facilities, historic places, or other visually sensitive land uses within a 8 km radius. Two state-owned lands, Lake Darling and Deer River Access, are located within 24 km of the site.

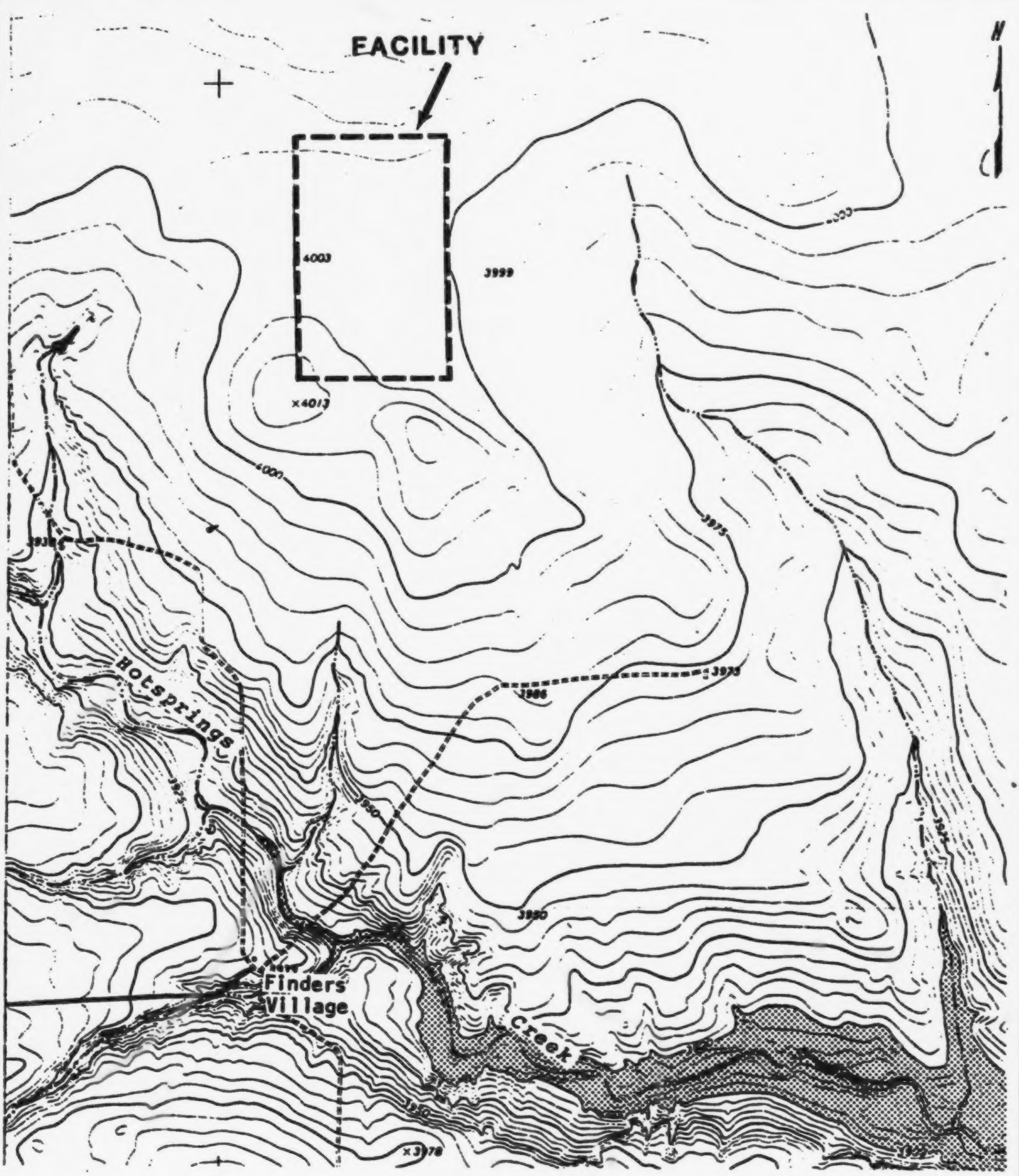
The chief source of economically important resources in the state lies in the substantial coal resources associated with Pennsylvanian age rocks. No such deposits occur under the site as the initial bedrock encountered is of Mississipian age. There is a potential for some natural gas deposits. However, the Ordivician source rocks are thin, making recovery unconsequential and uneconomical.

Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is equal to 93. The average cation exchange capacity of the subsurface media is about 12 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 85 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 30 years. The horizontal saturated zone travel times from the edge of the vertical projection onto saturated zone of the disposal cell closest to the discharge locations are as follows: to the restricted area fence, 90 years (30 m), to the closest drinking water well, 2,070 years (1250 m), and to the nearest surface water discharge location, 3,770 years (2500 m).

C.1.4 Southwestern Site

The southwestern site is assumed to be located within the Northern High Plains subdivision of the Great Plains physiographic province. The regional topography shows sharply contrasting flat plains and rolling to rugged erosional breaks. The general topography of the site is shown in Figure C.20.



FACILITY
N
4003
3999
×4013
4000
3975
3986
3950
Hotsprings
Finders Village
Creek
×3978

SOUTHWESTERN SITE TOPOGRAPHIC MAP

0 500 1000
SCALE IN METERS

0 1000 2000
SCALE IN FEET

KEY:

▨ 500 YEAR FLOODWAY

DAMES & MOORE

FIGURE C.20

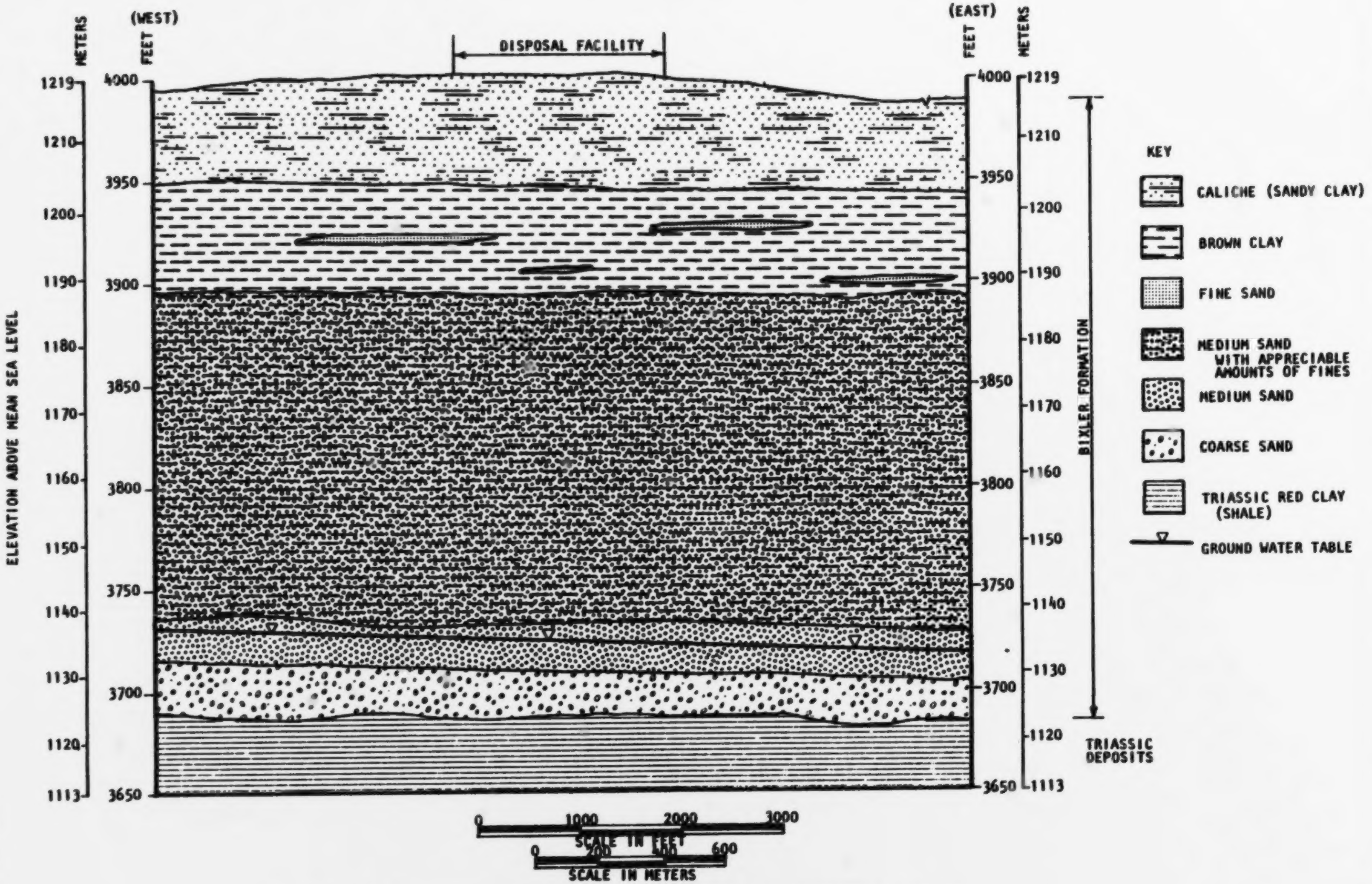
The plains are about 17,872 km^2 (6,900 mi^2) in areal extent and show a gradual eastward slope on the order of 0.2%. The site has an estimated average elevation of 1219 m (4,000 ft) above mean sea level. Drainage is to the southeast and southwest to various intermittant branches of Hotsprings Creek.

Geology

Below the surface cover of loam and clay-loam soil are Pliocene age deposits of the Bixler formation. These sediments were eroded from the ancient Rocky mountains and transported by streams to this area. Because of their origin of deposition, their character varies both vertically and horizontally. As a general rule, however, the sand and gravels are in the basal portion of the formation.

The Bixler Formation is about 91 m (300 ft) thick in the site area. The upper 12 to 15 m (40 to 50 ft) is composed of caliche, a calcium-rich, carbonate-impermeable sandy clay which acts in a similar manner as a hardpan. Effects of the semi-arid climate have cracked the upper 0.9 to 1.5 m (3 to 5 ft) of the caliche. Underlying the caliche is approximately 15 m (50 ft) of dense, brown clay. Thin, discontinuous streaks of sand are also associated with the clays. The balance of the Bixler is principally composed of sand and gravel, extending down to the eroded surface of the Triassic rocks.

The Triassic shales and sandstone belonging to the Maxwell group are estimated to be about 152 m (500 ft) thick in the site area. The first material encountered under the permeable Bixler strata is a red clay, indicative of the weathered shale surface. A schematic representation of the site geology is shown in Figure C.21. The site falls within an area designated as having a peak horizontal ground acceleration of less than 0.04 g with a recurrance interval of more than 500 years. No evidence was found to indicate the occurrance of capable faults under or near the site.


(WEST)
(EAST)
DISPOSAL FACILITY
METERS
FEET
1219
1210
1200
1190
1180
1170
1160
1150
1140
1130
1120
1113
4000
3950
3900
3850
3800
3750
3700
3650
ELEVATION ABOVE MEAN SEA LEVEL
BIXLER FORMATION
TRIASSIC DEPOSITS
KEY
CALICHE (SANDY CLAY)
BROWN CLAY
FINE SAND
MEDIUM SAND WITH APPRECIABLE AMOUNTS OF FINES
MEDIUM SAND
COARSE SAND
TRIASSIC RED CLAY (SHALE)
GROUND WATER TABLE
0
1000
2000
3000
SCALE IN FEET
0
200
400
600
SCALE IN METERS

GEOLOGIC PROFILE OF THE SOUTHWESTERN SITE

FIGURE C.21

385

Soils

The predominant soil types underlying the site are loams and clay loams belonging to the Starble, Nester, Wixman and Jeeper series. They were formed from moderately fine-textured, calcareous, wind-blown sediments derived mostly from alluvial outwash from the Rocky Mountains. Because rainfall is low, and there are long, dry periods, soil development has been slow. The soils are seldom wet below the root zone, and, as a result, many of the soils have a horizon of powdery lime accumulation. Leaching has not yet removed free lime from the upper layers of the calcareous Starble and Wixman soils. Soils of the Nester and Jeeper series tend to be more neutral.

Calcium contents are high in all the soils. Generally, the prairie type of vegetation contributes large amounts of organic matter to the soil. The soils are rather deep (up to 2.5 m) and well-drained, having nearly level to gentle slopes. Runoff is generally slow and permeability values range between less than 1.5 to 50 mm/hr (0.06 to 2.0 in/hr).

Ground Water

The Bixler formation is an unconfined aquifer with very limited consumptive use. The water occurs under water-table conditions, and the differences in the thickness of the water saturated material are closely related to the thickness of the Bixler formation. The saturated thickness under the site is only about 7.6 m (25 ft) as the water table lies some 84 m (275 ft) below ground surface. Available data indicates that the Bixler is the local source for recharge to the Triassic rocks where they are in contact.

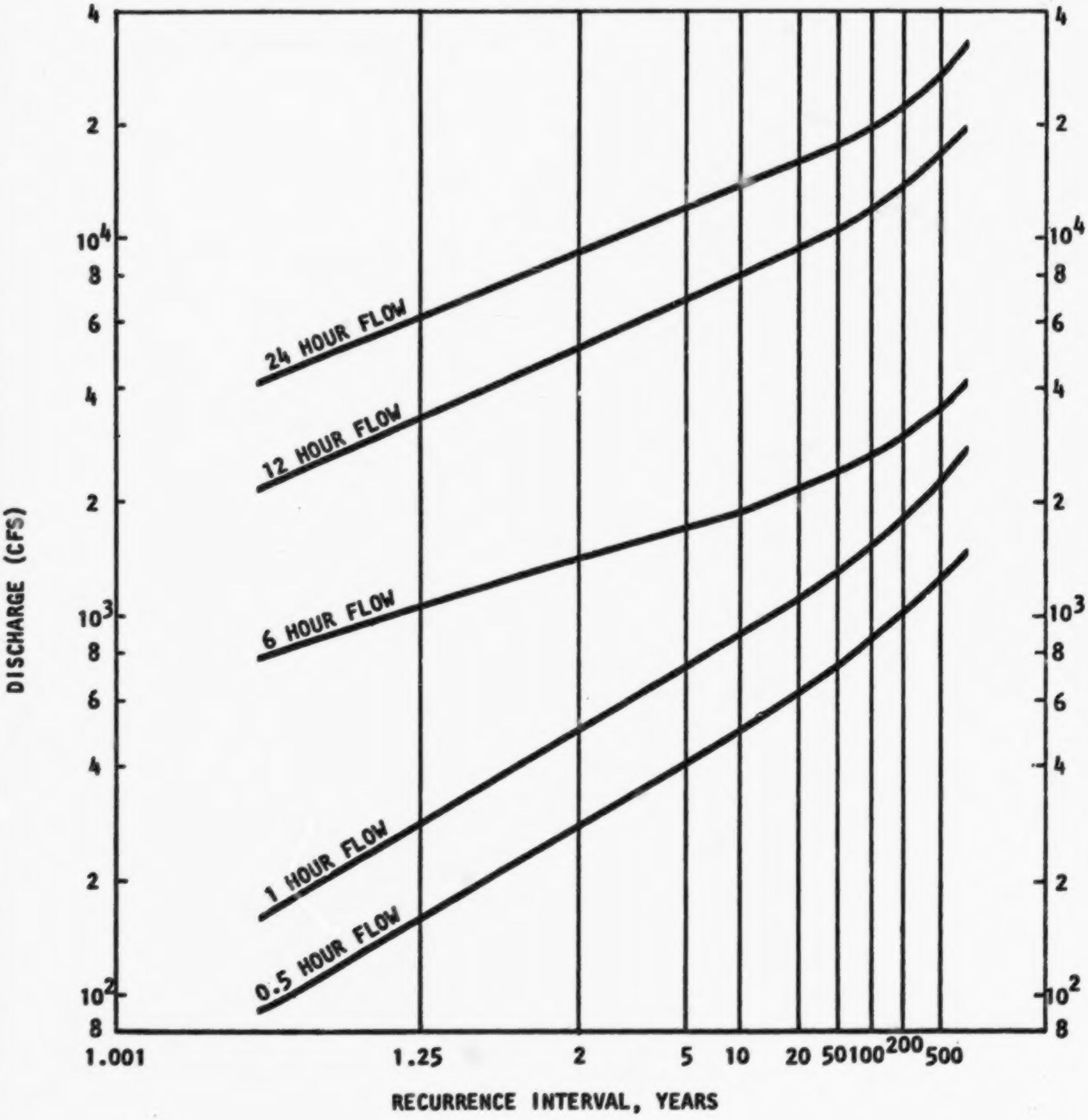
The source of water (recharge) to the Bixler, and thence to the Triassic rocks, is precipitation on its more permeable surfaces. The amount of precipitation that enters the ground water is a very small percentage of the total precipitation falling at the surface. It has been estimated that the quantity of precipitation annually reaching the groundwater is negligible. For the purposes of this report, however, it is assumed that the annual percolation is 1 mm. Due to the rather impervious nature of the onsite surficial materials, most of the precipitation will be lost by evaporation or drain to Hotsprings Creek as runoff. Part of this runoff will percolate downward through the coarser stream deposits and enter the ground water regime. Some infiltration may work its way through the fractured portions of the caliche and slowly downward to the water table, but this is of limited quantity.

Under natural hydraulic gradient conditions, the water table slopes to the east, generally parallel to the surface slope which is about 0.2%. The average permeability of the Bixler-Triassic aquifer in this area is estimated to be 4.7×10^{-3} to 9.4×10^{-3} cm/sec (100 to 200 gpd/ft^2).

Ground water within the site vicinity is used almost exclusively as a supply for livestock with a few domestic wells serving ranches. The wells are generally powered by windmills and generate yields not likely to be greater than 7.6 to 11.4 liters/min (2 - 3 gpm). The nearest irrigation well is located about 13 km (8 mi) from the site.

Surface Water

Elevations in the site vicinity range between 1169 and 1223 m (3835 and 4013 ft) above mean sea level. Total stream length above the site is over 90 km (295,680 ft). With the limited precipitation in the region, streams flow intermittantly throughout the year. A wide variation in discharge occurs at the site. Since no base flow is known to occur in the area, precipitation accounts for all of the stream discharge. Short duration, high intensity thunderstorms account for the peak discharges from the site. Flow recurrance intervals for the site vicinity are shown in Figure C.22.



FLOW RECURRENCE INTERVALS FOR THE SOUTHWESTERN SITE

DAMES & MOORE

FIGURE C.22

The area of the basin receives considerable intense rain (greater than 50 mm/hr), however, most peak flow is dissipated before discharge at the outlet. Peak discharge occurs when the rain event is within 32 km (20 mi) of the outlet. Analysis of the unit hydrograph of the site area and flow data indicate that discharge rates of up to 28.2 m^3/sec (1,100 cfs) may be expected to occur at least once a year. The 500 year flood has been determined to be approximately 736 m^3/sec (26,000 cfs) and the floodway is delineated on Figure C.20. As shown, the site is well above the floodway.

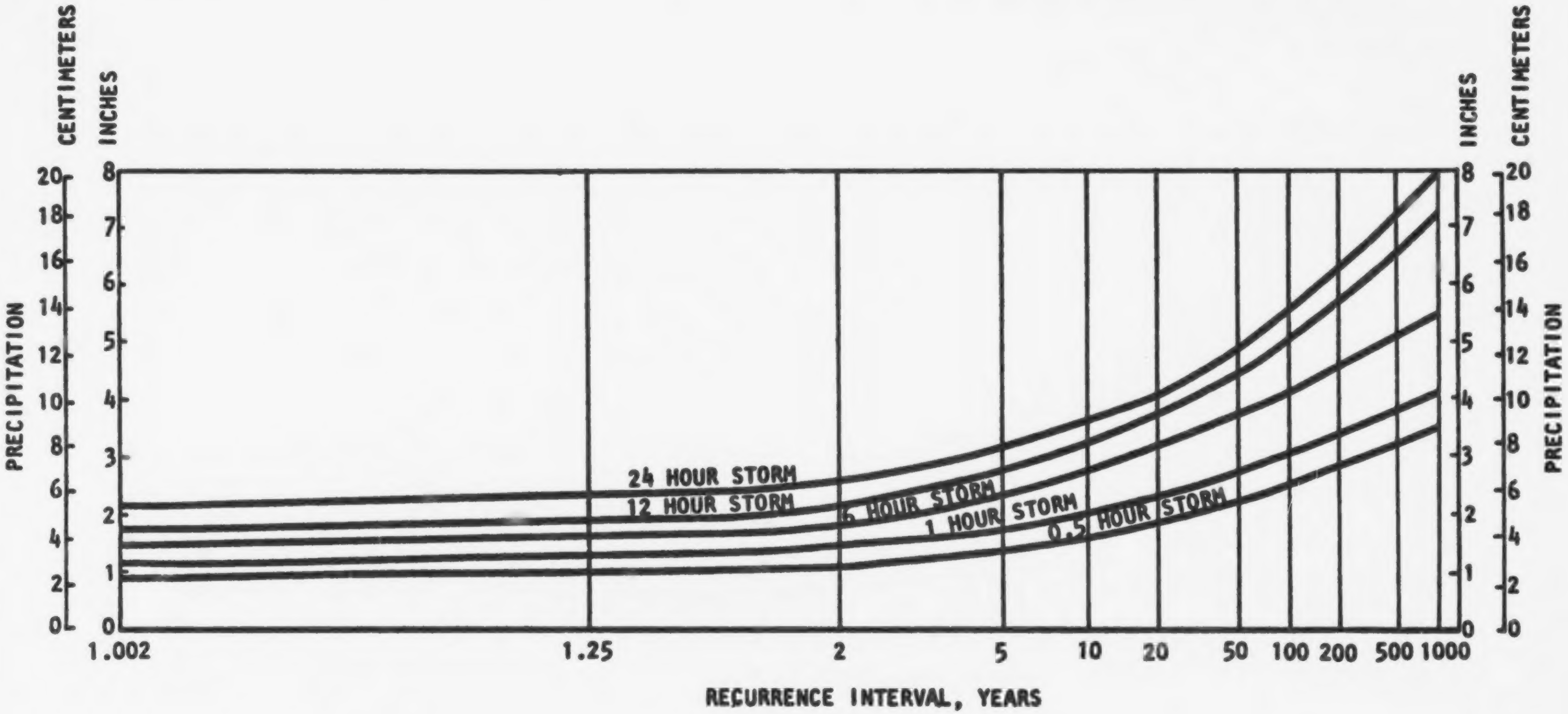
Meteorology

The climate of this site is considered semi-arid, which is characterized by low humidity, wide temperature and precipitation variations, and frequent windstorms. The average annual precipitation for the site area is approximately 485 mm (19 inches). Departures from the norm can be great with extreme yearly totals ranging from 243 to 1010 mm (9.56 to 39.75 in). Nearly three-quarters of the total annual precipitation occurs during the growing season from April through September, primarily in the form of thundershowers. Precipitation event recurrance intervals for the site are shown in Figure C.23.

The average annual temperature for the area is about 14°C (57°F). Maximum temperatures occur in the mid-summer months of June, July and August. The temperature characteristics of the site are shown in Figure C.24.

Rapid and wide temperature variations are common, especially during the winter months when cold fronts from the Rocky Mountain and Plains States sweep across the plains. Temperature drops up to 16°C (60°F) occurring within a 12-hour period may be associated with these fronts. The highest recorded temperature in the region was 42°C (108°F) and the lowest was -27°C (-16°F).

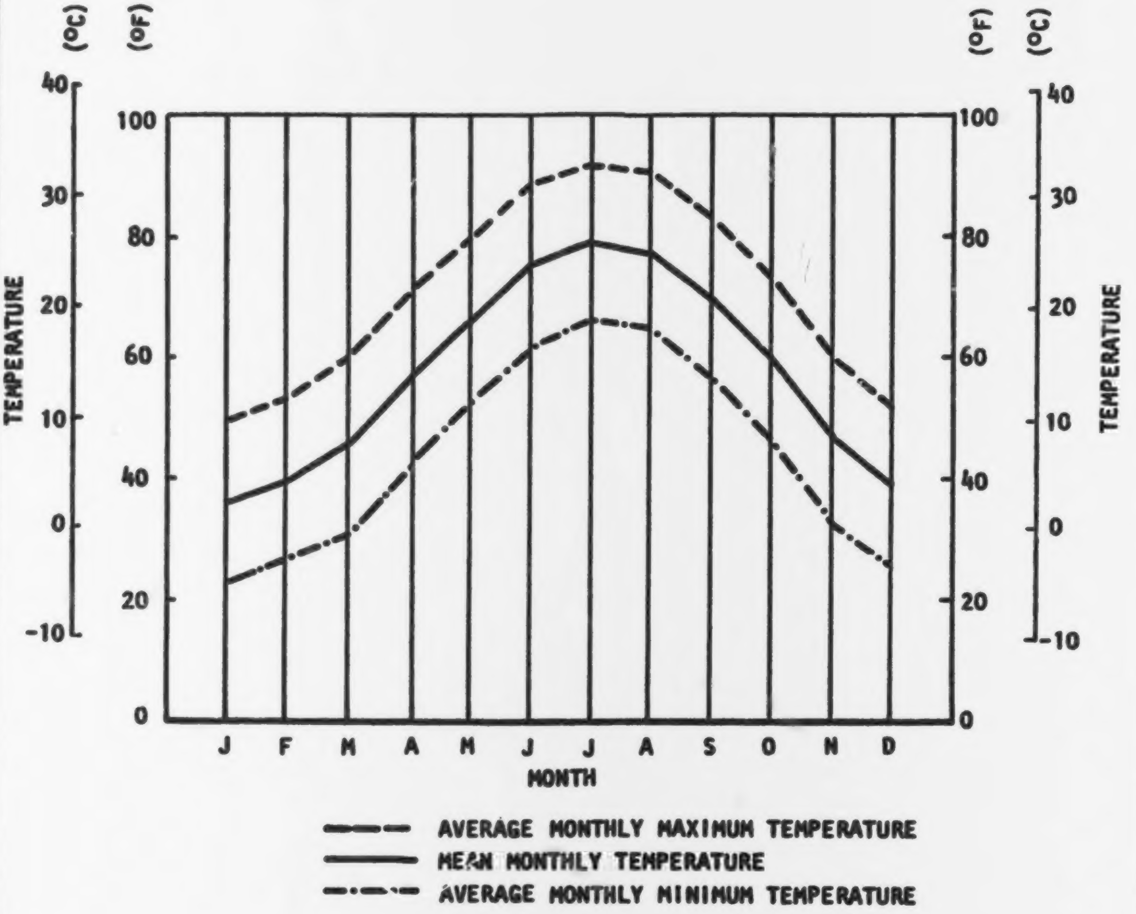
C-36



PRECIPITATION EVENT RECURRENCE INTERVALS FOR THE SOUTHWESTERN SITE

DAMES & MOORE

FIGURE C.23



MEAN MONTHLY TEMPERATURE AND AVERAGE OF THE MONTHLY MAXIMUM AND MINIMUM TEMPERATURES IN THE VICINITY OF THE SOUTHWESTERN SITE

DAMES & MOORE

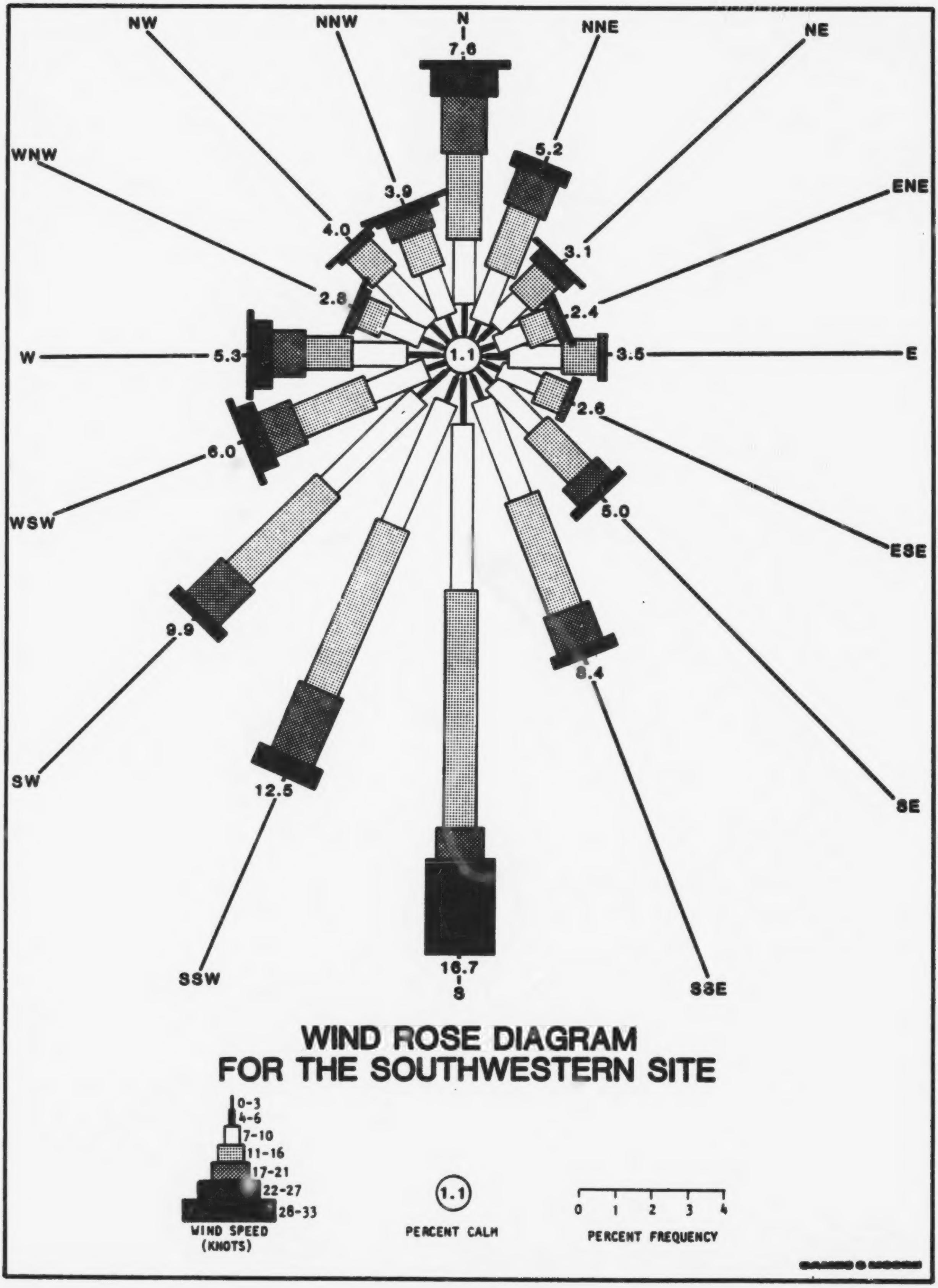
FIGURE C.24

The prevailing winds from March through October are southerly at 25 km/hr (13.6 knots), and southwesterly at 21 km (11.4 knots) during the winter months. The annual mean speed for all directional components is 24 km (13 knots) and southerly. These winds contribute to the evaporation rate associated with the region. The strongest winds generally occur in March and April and are associated with thunderstorm activity. The strongest winds recorded (134 km/hr in 1949) were associated with a tornado, however these climatic events are rare. The wind rose diagram for the site is shown in Figure C.25.

Terrestrial Ecology

The site is located in the High Plains area, also known as the Tinson Province. This area is a relatively level high plateau, and is better drained than most of the other regions in the state. The shorter growing season (179 - 225 days) and lower annual average temperature (12° to 13°C) found in this region, compared to other parts of the state, play an important role in the types of plants and animals found here.

The area has been characterized (within a 40 km radius of the site) as Grama Buffalo Grasslands. The most abundant native plant species in this short grass/mixed grass prairie are buffalograss and blue grama. Total ground cover is relatively dense, and tends to increase under grazing. The preponderance of grass species results in large quantities of organic materials in the form of living and dead grass roots within the first ten to twelve centimeters of soil (some roots of blue grama and buffalo grass extend to 0.9 m, however). The vegetative cover of the site is typical of the region. Although various species of trees, including oaks, elms and hackberries, are often found along stream floodplains and steep-walled canyons, these are not found along Hotsprings Creek, an intermittant stream, or its feeder streams, which surround the all but northern portions of the site. Federally declared endangered species have not been observed within the site.



WIND ROSE DIAGRAM
FOR THE SOUTHWESTERN SITE

~~C-57~~ 343

FIGURE C.25

The mammalian fauna of this general area includes at least 50 to 60 species, two of which are restricted to this area of the state: the swift fox and plains pocket mouse. During the hot daylight hours, a large number of mammals of this semi-arid region live in burrows which they either dig themselves, or which they share or overtake from other species. The larger species which create their own underground burrows include the badger, plains pocket gopher, and swift fox. Only the former two species were observed within 1 km of the site. The fox uses its burrow, which averages 3.7 m (12 ft) in length and 81 cm (32 inches) in depth, as a den. Many other species also dig their own burrows, or use those of others, to escape the heat and predators, to search for food (insects, seeds or other burrowing mammals) or to use as dens. However, these burrows are shallow.

Other non-burrowing mammals characteristic of this area and which have been observed onsite include the coyote, pronghorn antelope, bobcat, jackrabbit, and eastern cottontail. While six species of bats are known to inhabit the county, none were observed to nest at the site. The most common game species found on the site are rabbit, quail, dove and pheasant.

The mixed grass prairie found onsite and in the general area does afford suitable habitat to numerous resident bird species. The most common small birds include the Western meadowlark, dickcissel, bobolink, savanna sparrow, and prairie chicken. The most numerous resident birds of prey include the golden eagle, horned owl and burrowing owl.

Several species of lizards and snakes also inhabit the site. The more common ones include the northern earless lizard, prairie lizard, great plains skink, prairie rattlesnake, western diamondback rattlesnake, and bullsnake. Only the last two species have been observed within the site boundaries. As with many mammals of this region, these reptiles extensively utilize underground burrows. Most of the snakes use rodent burrows both for cover and in search of food. The great plains toad and plains and western spadefoot toads dig their own underground tunnels, which can range from several centimeters to a meter in depth.

Aquatic Ecology

The aquatic environment of the site is limited to Hotsprings Creek and its two feeder streams, all intermittent, which surround the site to the east, west, and south. This creek remains intermittent until approximately nine miles prior to its confluence with the Montreel River approximately 136 km (85 mi) downstream. The only other tributories to Hotsprings Creek occur within an 8 km (5 mi) radius of the site. After rainstorms when water does flow in this stream, aquatic biota is limited to algae, insects (which use the water to breed), and potential fish species such as minnows and sunfish. These fish survive the dry seasons by gathering in small pools of water that may remain throughout the year, and are then dispersed throughout the stream with the flowing waters.

Land Use

The site is located near the administrative borders of a national grassland administered by the U.S. Department of Agriculture, on open grassland. The site itself was privately owned before purchase by the state. There are no residences onsite or within the close vicinity (1 mi) of the site.

The site region is a plain containing numerous parcels of federal grassland, distributed throughout this portion of the state and into neighboring states. Portions of the site are used at times for grazing cattle. The national grassland is the overriding factor influencing land use in the area, and this is not expected to change significantly in the foreseeable future.

The only known mineral resource occurring in the site area is caliche. This calcium carbonate cement is associated with sand and gravel deposits of the Bixler formation, and may be suitable for use as aggregate. However, these deposits are widespread throughout the entire region and do not represent unique resources.

Whereas numerous producing oil and gas wells have been drilled in the adjoining county to the east of the site, no historical production has occurred within the site county. Prospect wells drilled within proximity to the site have not indicated the presence of oil or gas reserves of recoverable quantity.

Other Parameters

Several other parameters are utilized in the impact analysis. These are estimated to be the following. The precipitation-evaporation (PE) index of the vicinity is equal to 21. The average cation exchange capacity of the subsurface media is about 5 milliequivalents per 100 grams (meq/100 g). The average silt content of the site soils is 65 percent. The vertical water travel time from the bottom of the trenches to the saturated zone is 275 years. The horizontal saturated zone travel times from the edge of the vertical projection onto saturated zone of the disposal cell closest to the discharge locations are as follows: to the restricted area fence, 5 years (30 m); to the closest drinking water well, 300 years (3000 m); and to the nearest surface water discharge location, 600 years (6000 m).

C.1.5 Summary of Regional Environmental Parameters

This section presents a summary of the regional environmental parameters and characteristics presented in this appendix and used in this report to calculate radiological and economic impacts from LLW management and disposal.

The assumed population distribution in the vicinity of each of the 4 regional sites at the year 2000 (postulated year of end of facility operations) is presented in Table C-1.

Water balance calculations for determining the amount of precipitation reaching the saturated zones of the regional sites (i.e., the amount of percolation) were presented in Tables A-4 and A-5. As shown in Table A-5, the water balance calculations for the southwestern regional site indicate that there is no calculable percolation reaching the saturated zone. However, for purposes of determining bounding impacts from waste disposed at this site, it is assumed that the percolation coefficient equals 1 mm at the southwestern site.

Based upon this information and information presented in sections C.1.1 through C.1.4, environmental parameters specific to the four regional disposal sites may be calculated. A list of the region-dependent parameters was included in Table 3-2, together with the parameter symbols used in the computer codes developed as part of this work. Values determined for each of these parameters for each of the four regional sites are provided in Table C-2.

Use of a specific set of property values to calculate impacts is determined by the value of the region index, IR. The transfer factors for the accident, intruder-construction, intruder-agriculture, and exposed waste scenarios are used to calculate the site selection factors (f_s) for these scenarios as described in Chapter 3.0 and Appendix A of this report. The parameters for the ground water scenarios are used to calculate the waste form and package factors (f_w) and the site selection factors (f_s) for these scenarios as described in Section 3.5 and Appendix A. The transportation parameters are used to calculate radiological and economic impacts of waste transport to the regional disposal sites as described in Chapter 4.0. Additional information regarding the use of the parameters in the computer codes is provided in Chapter 6.0.

TABLE C-1 . Population Distributions for Regional Case Studies

Distance From Facility	North east	South east	Mid west	South west
0-5 miles	3,440	2,024	3,070	59
5-10 miles	20,513	8,115	4,998	180
10-20 miles	73,636	36,000	27,890	3,529
20-30 miles	121,559	124,995	104,181	9,062
30-40 miles	556,639	203,435	121,893	4,888
40-50 miles	1,012,788	104,933	359,146	27,158

TABLE C-2 . Environmental Parameters for Regional Locations

Parameter	Symbol	North east	South east	Mid west	South west
Accident Scenario					
Fire	TPO(1)	1.83E-10	1.83E-10	1.83E-10	1.83E-10
Single-Container	TPO(2)	2.61E-12	3.32E-12	2.55E-12	1.79E-12
Intruder Scenarios					
Construction	FSC	9.18E-12	2.01E-11	2.51E-11	2.64E-10
Agriculture	FSA	2.96E-11	3.18E-11	3.28E-11	8.06E-11
Exposed Waste Scenario					
Intruder-Air	POP(1)	1.01E-09	3.50E-10	3.86E-10	2.66E-11
Erosion-Air	POP(2)	1.51E-09	5.25E-10	5.79E-10	3.99E-11
Surface Water	POP(3)	1.12E-07	1.12E-07	1.12E-07	1.12E-07
Groundwater Scenario					
Travel Times - years					
Between Sectors	DTTM	400	64	120	8
Individual Well	TTM(1)	200	42	130	280
Boundary Well		350	66	175	283
Population Well	TTM(2)	2500	400	2100	580
Population Surface	TTM(3)	5000	800	3800	880
Peclet Numbers					
Between Sectors	DTPC	800	1600	800	800
Individual Well	TPC(1)	400	1300	400	1300
Boundary Well		700	1900	700	1600
Population Well	TPC(2)	10000	10000	12500	30000
Population Surface	TPC(3)	20000	20000	25000	60000
Dilution Factors - m^3					
Individual Well	QFC(1)	7700	7700	7700	7700
Population Well	QFC(2)	2.0E+5	2.0E+5	2.0E+5	2.0E+5
Population Surface	QFC(3)	4.5E+6	4.5E+6	4.5E+6	4.5E+6
Geometric Reduction					
Individual Well	RGF(1)	1	1	1	1
Population Well	RGF(2)	1	1	1	1
Population Surface	RGF(3)	1	1	1	1
Percolation - mm					
Regular Cover		74	180	50	1
Thick Cover		38	30	25	1
Retardation Coefficient Set Used	NRET	4	3	3	2
Transportation					
Oneway Distance (mi)	DIST	300	400	600	1000
Stops Along the Way	STPS	1	1	2	3
Cask Turnaround(days)	CASK	2	3	5	8

C.2 Reference Disposal Facility Design and Operation

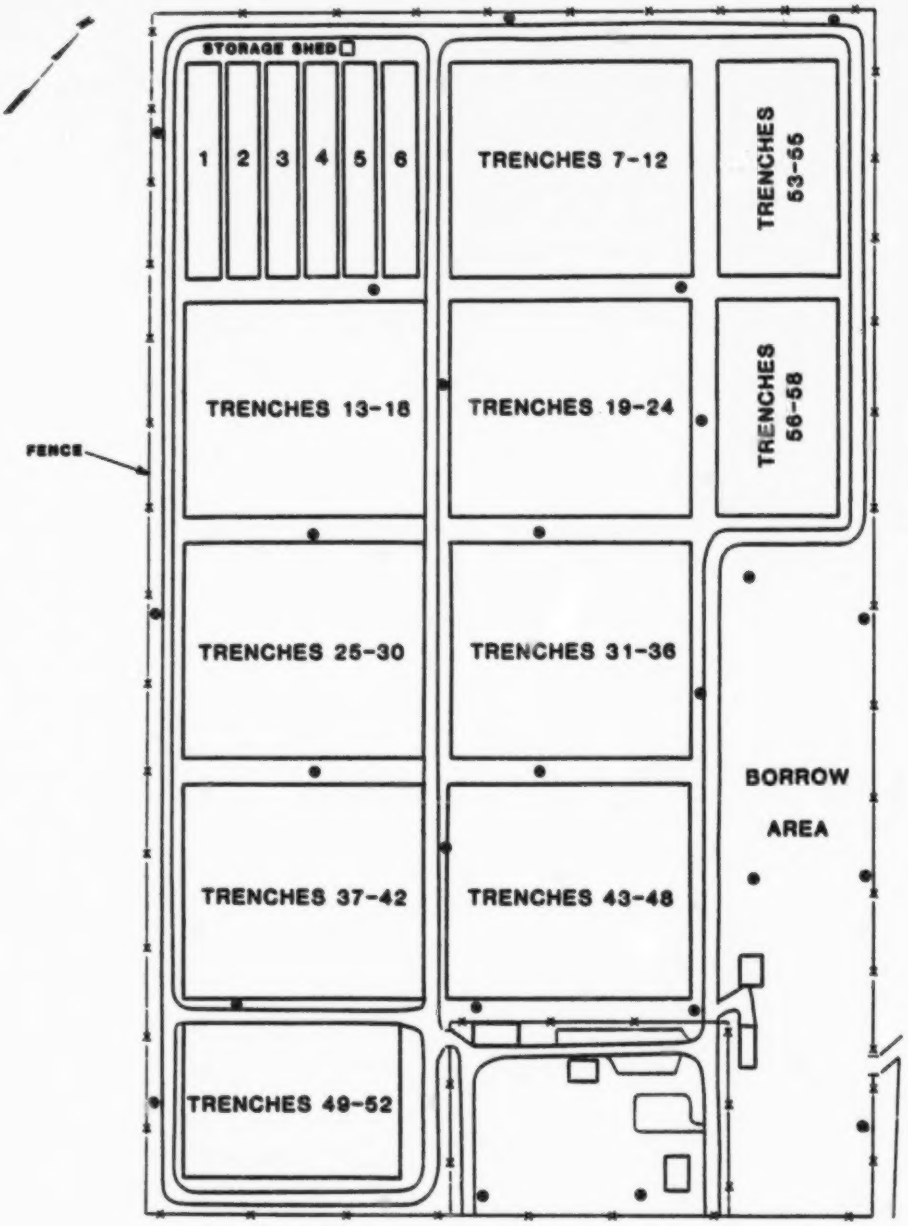
In this section, a reference near-surface disposal facility design is described, including the support facilities and structures, and facility operations. The reference disposal facility design is meant to be representative of existing disposal facilities and operating practices and has been condensed from reference 2. The reference near-surface disposal facility design is then assumed to be located at each of the four hypothetical regional disposal facility sites described in the previous section C.1. From this basic design, the impact measures associated with LLW management and disposal may be assessed on a regional basis as a function of alternative waste forms and alternative disposal facility design and operating practices.

C.2.1 Basic Design

To provide a base case against which alternatives can be analyzed, the assumed disposal facility design is sufficient for a total waste capacity of up to one million m^3 delivered to the disposal facility at an annual average rate of up to 50,000 m^3. The actual volume of waste disposed at one of the four regional disposal facilities is a function of the volume of waste generated in the region and the waste processing alternative (waste spectrum) considered.

To develop the disposal facility, the licensee is assumed in all regions to purchase a plot of land covering 81 ha (200 acres), of which 60 ha (148 acres) is turned over to state ownership. This 60 ha of land is then leased back to the licensee and is used by the licensee for the disposal facility. The remaining 21 ha (52 acres) is retained by the licensee for possible future use.

A conceptual layout of the reference disposal facility design is illustrated in Figures C-26 and C-27. As shown in the figures, the disposal facility may be divided into two basic areas: a "restricted


STORAGE SHED
1
2
3
4
5
6
TRENCHES 7-12
TRENCHES 53-55
TRENCHES 13-18
TRENCHES 19-24
TRENCHES 56-58
FENCE
TRENCHES 25-30
TRENCHES 31-36
BORROW AREA
TRENCHES 37-42
TRENCHES 43-48
TRENCHES 49-52

REFERENCE DISPOSAL SITE LAYOUT

0 50 100

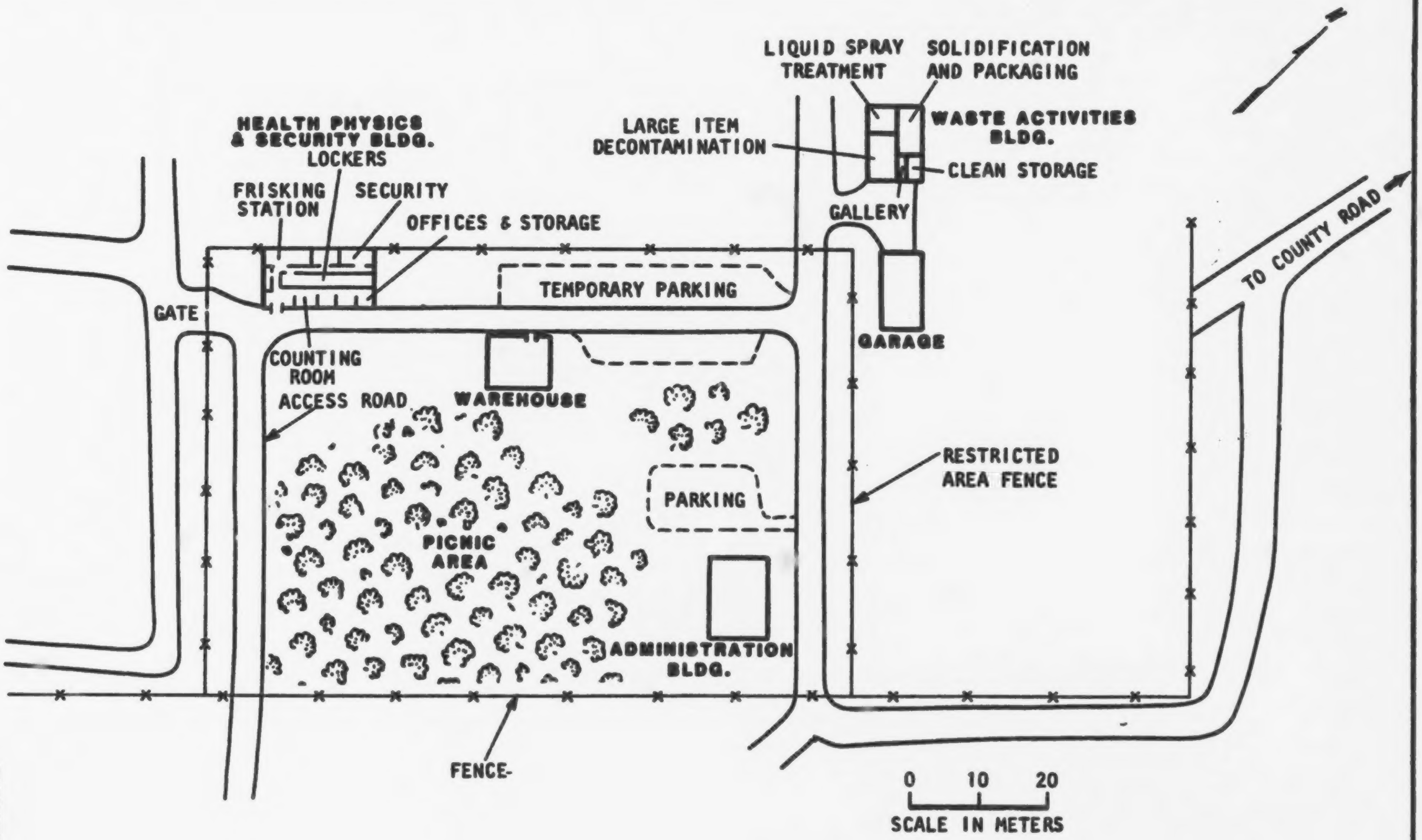
SCALE IN METERS

KEY:

● MONITORING WELLS

FIGURE C.26

~~C-68~~


LIQUID SPRAY TREATMENT
SOLIDIFICATION AND PACKAGING
WASTE ACTIVITIES BLDG.
LARGE ITEM DECONTAMINATION
CLEAN STORAGE
GALLERY
HEALTH PHYSICS & SECURITY BLDG.
LOCKERS
FRISKING STATION
SECURITY
OFFICES & STORAGE
TEMPORARY PARKING
GATE
COUNTING ROOM
ACCESS ROAD
WAREHOUSE
GARAGE
TO COUNTY ROAD
RESTRICTED AREA FENCE
PARKING
PICNIC AREA
ADMINISTRATION BLDG.
FENCE
0
10
20
SCALE IN METERS

SUPPORT FACILITIES

FIGURE C.27

DAMES & MOORE

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area" and an "administration area". The restricted area includes a "disposal area", in which disposal of radioactive waste takes place, as well as an "operational area".

The restricted area includes a buffer zone between the disposal trenches and the restricted area fence of 30 m (100 ft). As shown in Figure C-26, the operational area is located along the eastern side of the disposal facility and is used as a borrow area, for cask storage, and for other miscellaneous functions. The operational area includes two facilities, a decontamination facility and a garage, which are used to support waste disposal operations. The administration area is located near the eastern corner of the disposal facility and is considered uncontrolled by the licensee for purposes of radiation protection. The administration area includes support facilities plus parking space for employees as well as for incoming waste delivery vehicles.

The reference facility design occupies a total of 60 ha (148 acres), including the disposal area, operational area, and administration area. As is the case at existing disposal facilities, however, considerably less than the total site acreage is used for waste disposal. For example, specific areas of a particular disposal site may not be suitable for waste disposal due to geohydrological or topographical reasons.

The administration area occupies 3.7 ha (9.1 acres), and is assumed to be a constant for all waste form and facility design and operation alternatives considered. The area of the land committed for waste disposal (in other words, the land actually containing disposed radioactive waste) varies according to the alternatives considered. For example, about 35 ha (86 acres) would be required for random disposal of one million m^3 of waste into trenches having average dimensions of 180 m long by 30 m wide by 8 m deep, and having an average spacing of 3 m between each trench. The remaining 21.6 ha (53 acres) includes the operational area and the 30 m buffer zone as well as any excess land within the disposal area used for roads, working areas, and so forth.

The entire disposal facility is surrounded by a 2.4 m (8 ft) high chain-link fence topped with three strands of barbed wire. A 2.4 m high fence also separates the administration area from the restricted area. Access to the disposal facility is via two short gravel roads. There are no rail facilities. Incoming waste delivery and employee vehicles enter the facility through one of two gates located in the administration area. These gates are locked at night and at other times when the site is not being operated. Access to the restricted area is controlled by security check points near the gates in the fence separating the administration area and the restricted area.

For security purposes, a narrow gravel road runs alongside the inside of the fence surrounding the restricted area. Other on-site gravel roads wide enough to accommodate two small vehicles lead to the active disposal areas and are constructed by the licensee as needed. A lighting system is provided around the site perimeter and also in the operational and administration area. There are no other lights installed in the interior of the restricted area.

The average disposal trench size assumed in this report is 180 m (591 ft) long by 30 m (100 ft) wide by 8 m (26 ft) deep. The length and width of the disposal trenches may vary somewhat (about ± 10 m), however, depending on the availability of disposal space. The rather large trench sizes assumed in this report are representative of recent trends at existing disposal sites. Fifty-eight such trenches would be required for random disposal of one million m^3 of waste.

As a trench is constructed, the locations of the four corners of the trench are surveyed and referenced to a bench mark. An approximate one degree slope is provided in the bottom of a trench from end to end and from one side toward a 0.6 m x 0.6 m (2 ft x 2 ft) gravel-filled French drain. The French drain runs the entire length on the lower elevation side to provide for collection of any liquid drainage that might might occur. A gravel-filled sump is located at the low corner of the trench.

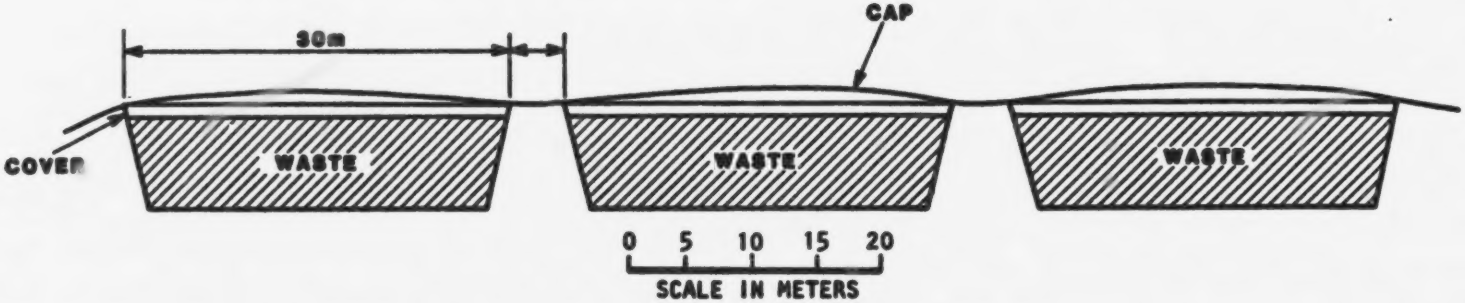
Each trench is equipped with a minimum of three 0.15 m (6 in) diameter polyvinyl chloride (PVC) standpipes located within the French drain and standing along the sidewalls of the trench. Two of the three standpipes are located at each end of the excavation. The third standpipe is usually located at the trench midpoint (also standing in the French drain). These PVC standpipes function as observation wells or sumps. A typical trench cross section is shown in Figure C.28.

C.2.2 Support Facilities and Structures

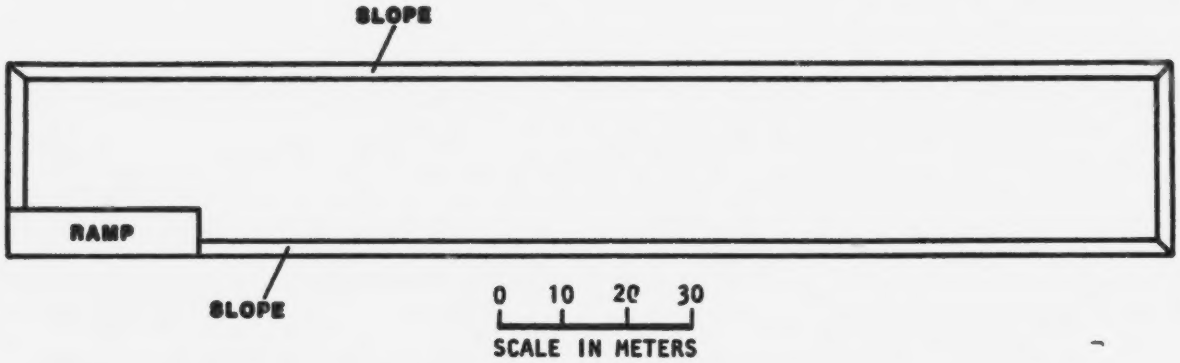
The support facilities include (1) an administration building, (2) a health physics/security building, (3) a warehouse, (4) a garage, and (5) a waste activities building. All structures at the site are one-story metallic structures on concrete pad foundations. The building areas for these five major structures are listed below:

	Area	
Building or Facility	m^2	ft^2
Administration	625	6,725
Health Physics/Security	800	8,610
Warehouse	470	5,060
Garage Mechanics	420	4,520
Waste Activities	560	6,025
Storage Shed	80	860

The administration building contains office space for site management and other administrative personnel working at the site. The activities performed within this building include coordination of waste shipments to the site, billing customers, and other routing of file work. Site records are also stored within this building.


CAP
30m
COVER
WASTE
WASTE
WASTE
0 5 10 15 20
SCALE IN METERS

TYPICAL TRENCH CROSS-SECTION


SLOPE
RAMP
SLOPE
0 10 20 30
SCALE IN METERS

PLAN VIEW OF TYPICAL TRENCH

DAMES & MOORE

FIGURE C.28

TYPICAL TRENCH DETAILS

The health physics/security building serves as the focal point for the majority of disposal activities at the site. This building houses a security section, a counting room, health physics offices, a change room/locker room, a lunch area, and a supply room. A safety decontamination shower is located adjacent to the frisker location. Emergency equipment such as safety ladders, respiration equipment, and anti-contamination suits are stored in the vicinity of the frisker station. The employee change/locker room includes both a street clothes ("clean") and work clothes area. Showers are also located in this section of the building.

The warehouse is used to store supplies used on site. This facility is located within the administration area so that delivery trucks need not enter the disposal area. Among the stored items in this warehouse are cables, hooks, drums, bags, and other miscellaneous hardware. Casks and site vehicles are stored in the operational area.

The garage is located in the restricted area and only vehicles and equipment that have been surveyed and decontaminated to within specified limits use this facility. The garage is large enough to hold two vehicles at a time for maintenance. Mechanic's tools, spare parts, oil, and fuel (adjacent to the building in underground tanks) are also stored in this garage.

The waste activities building houses several functional areas including (1) a large item decontamination bay, (2) a control room for the decontamination bay, (3) a liquid treatment system, (4) a waste solidification, packaging, and overpacking area, (5) a supply room, and (6) a small waste storage area.

The decontamination bay is used for washing down (decontaminating) large pieces of equipment (including trucks if necessary) through the use of a high-pressure recirculating water supply system. Contaminated liquids resulting from decontamination operations are collected, treated in the liquid treatment facility, and then recirculated. Contamination levels in these solutions are generally quite low, however, water treatment is applied to recirculating fluids. Small-scale decontamination of tools and other small items may be accomplished within the solidification staging area. The solidification area includes batch concrete mixing equipment for solidification of small quantities of low-activity liquids. A small storage area is provided for occasional temporary storage of shipments received from common carriers. A loading dock is located along the southern corner of this building.

A storage shed is used for supplies and miscellaneous tools used at the disposal trenches. This shed is portable and is usually located close to the active disposal trenches.

C.2.3 Site Operations

The regional near-surface disposal facilities are all assumed to be operated for profit by small corporations which are also involved in other nuclear-related business activities. The size of the facility staff required during the operational phase is a minimum of 70 people. The staff of 70 includes 7 upper-level management, 14 clerical personnel, 8 radiation technicians, 34 operational personnel for trench construction and waste emplacement, 3 quality assurance personnel, and 4 security guards. However, additional personnel may be required depending upon the facility design and operations alternatives considered.

The site operations discussed in this section include the following: waste receipt and inspection, waste storage, waste disposal, radiation and contamination control, site groundskeeping and maintenance, environmental monitoring, security, recordkeeping and reporting, and quality assurance.

Waste Receipt and Inspection

Shipments of radioactive waste arrive by truck and are processed onto the site on a first come, first served basis. Accompanying the shipments are manifest documents -- termed radioactive shipment records (RSR's) -- which describe the content of the shipment. Arriving shipments are inspected for compliance with applicable Federal regulations and waste acceptance criteria established as conditions in the disposal site license. The results of these inspections are recorded on radiation survey forms and summarized on the RSR's accompanying the waste shipments. Shipments found to be in compliance with Federal regulations and license conditions proceed into the disposal area for unloading. Violations of transportation regulations are reported to Federal and state authorities in compliance with Federal and state regulations and license conditions. Waste shipments which are not acceptable for disposal at the facility are returned to the shipper. Damaged or leaking waste packages are identified and appropriate protective or remedial action is taken. Depending upon license conditions, damaged or leaking waste containers may be overpacked or repackaged, and either accepted for disposal or returned to the sender. Free-standing liquids detected are removed and solidified. Activities such as overpacking and solidification are performed at the waste activities facility.

Waste Storage

Generally, waste received at the site is disposed within a few days. Waste that must be temporarily stored is generally left in transport vehicles. However, there may be a need to store waste packages in a designated storage area, especially if layering of high activity waste is practiced at the disposal facility. In such cases, packages may have to be stored until the proportion of high activity to low activity packages is acceptable for burial.

Waste Disposal

Waste is emplaced in the disposal trenches and the trench is then backfilled. Depending upon the alternatives considered, the backfill may be an earthen fill or a cement grout. License conditions require that backfill operations commence immediately if radiation readings greater than 100 mR/hr are recorded at the trench boundary, and continue until radiation levels are reduced below 100 mR/hr. License conditions also prohibit waste packages from being placed in standing water, so waste disposal commences at the high end of the trench and works down towards the lower end. Rainwater falling within the open trench and contacting the uncovered waste packages drains away to the lower end of the trench, where it is removed as necessary and treated by such methods as solar evaporation or solidification.

Waste is emplaced to within one meter of the top of the trench. The backfill material is spread over the trench and compacted using conventional means until the trench cover approximately corresponds to the original site surface. A one meter thick earthen cap is placed upon the backfill. The cap may be additionally covered with natural overburden material as necessary to provide good drainage characteristics and according to the final contours planned for the site surface.

During waste handling and diposal, operations are monitored to ensure radiation safety. After the transport vehicle is unloaded it is again surveyed for contaminaton and decontaminated, as necessary, prior to leaving the restricted area. The results of the survey are recorded on the accompanying RSR.

Site Groundskeeping and Maintenance

Groundskeeping includes both the upkeep of grounds and the maintenance of external building surfaces. Groundskeeping activities include contouring of the ground surface, emplacement of a soil cover material such as grass, fertilizing, mowing, etc. A site maintenance program entails routine inspection of site surfaces and fences for trench settlement, gullying, damage, debris, etc. Repairs are made as necessary.

Other Site Programs

A number of other programs are also carried out by the disposal facility by the site operator. These are discussed in detail in Reference 2, but briefly, include the following:

- site safety,
- enviromental monitoring,
- recordkeeping and reporting, and
- quality assurance.

The site safety program includes operations and procedures to ensure site safety, to control radioactive materials at the disposal facility, and to minimize potential off-site releases of contaminants. These include operations and procedures for personnel radiation monitoring, site radiation and contamination control, industrial safety, abnormal or emergency situations, and personnel monitoring.

The environmental monitoring program is carried out to detect movement of radionuclides from the disposal cels and to help assess long-term safety. A summary of the facility operational monitoring program is included as Table C-3. This program includes collection of well water samples, soil and vegetation samples, and air samples, as well as monitoring for direct gamma radiation levels.

The security program is carried out both for radiation health and safety considerations as well as to protect the many thousands of dollars worth of equipment, buildings, and facilities located on site. The security program includes security personnel, controlled access to facility areas, communication equipment, identification badges, and emergency procedures.

TABLE C-3 . Reference Facility Operational Monitoring Program

Sample Description	No. of Locations	Type	Frequency of Analysis	Type of Analysis
External Gamma (TLD)	50	Continous	Quarterly	Exposure
Air Particulates (filter)	3	Continous	Daily	Gross Beta-Gamma
Soil & Vegetation	10	Grab	Quarterly	Gross Beta-Gamma Gross Alpha HTO
Offsite Wells	5	Grab	Semi-Annual	Gamma Isotopic Gross Alpha HTO
Site Boundary Wells	10	Grab	Semi-Annual	Gamma Isotopic Gross Alpha HTO
Disposal Area Wells	15	Grab	Quarterly	Gamma Isotopic Gross Alpha HTO
Filled Disposal Trench Sumps	58	Grab	Monthly	Gamma Isotopic Gross Alpha HTO

Records are maintained by the site operators to cover the areas required by law, for operational control, and for future use. These include those for:

- personnel exposures;
- waste receipt and disposal;
- personnel training;
- quality assurance;
- environmental monitoring;
- operating procedures; and
- site surveillance and monitoring.

The quality assurance program functions as a parallel department which provides quality control and training support to facility operations. As part of this, a management audit program is carried out to maintain standards of radiological control and safety and to ensure compliance with federal, state, local, and site license requirements. The program includes a review of operating procedures and past exposure records, facility inspections, and surveillance of work being performed.

REFERENCES FOR APPENDIX C

1. Wild, R., et.al., Dames & Moore, "Data Base for Radioactive Waste Management. Volume 2. Waste Source Options," USNRC Report NUREG/CR-1759, to be published.
2. U.S. Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, "Draft Environmental Impact Statement on 10 CFR Part 61 : Licensing Requirements for Land Disposal of Radioactive Waste," NUREG-0782, to be published.

APPENDIX D

COMPUTER LISTINGS

APPENDIX D : COMPUTER LISTINGS

This appendix contains the listings for the computer programs and data files discussed in Chapter 6 of this report. The five programs are listed first and include, in order: INTRUDE, GRWATER, OPTIONS, INVERSI, AND INVERSW. The seven data files are listed secondly, and include three basic files (DATA, DATAD, and NUCS) as well as four spectral files.

The DATA and DATAD files contain the volumes and radionuclide concentrations of the 36 individual waste streams considered in the analyses, as well as the pathway dose conversion factors and other information specific to each of the 23 radionuclides considered. In the DATA file, the radionuclide concentrations are given as-generated. In the DATAD file, the radionuclide concentrations are given as-decayed to the end of the operating life of the reference disposal facility, assuming that the operating life is 20 years. Also included in these files are values for parameters used in the analyses which depend upon the environmental characteristics of the particular regional site considered. The NUCS file is similar to the DATA and DATAD files except that the waste stream volumes and radionuclide concentrations are omitted.

The four spectral files (SPC1, SPC2, SPC3, and SPC4) contain the values of the waste spectral incides which vary depending upon the waste spectrum considered. Values for waste spectrum 1 are given in SPC1, values for waste spectrum 2 are given in SPC2, and so forth.

Listing for INTRUDE Computer Code

```
      PROGRAM INTRUDE (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
C
C     TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
C       FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCK.
C     TAPE2 CONTAINS ISPC(SPECTRAL) FILE.
C     INPUT IS USED TO READ IRDC - DISPOSAL TECHNOLOGY INDICES.
C     TAPE3 CONTAINS DETAILED OUTPUT - FROM SUBROUTINE RCLAIM.
C     TAPE4 CONTAINS MAIN PROGRAM OUTPUT (INTRUDER IMPACTS).
C
      COMMON/PAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IRDC(12)
+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
+           RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+           /IMPS/DZD(7,2),DZ(7,2,9)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C
      DIMENSION NOTE(6),TYM(9),DES(2),IGRP(36),DEC(23,2)
      DATA NTYM/9/,TYM/50.,100.,150.,200.,300.,400.,500.,1.E3,2.E3/,
C          NGNX/36/,IGRP/1,2,3,4,5,6,7,8,9,10,11,12,13,14,
C                         15,16,17,18,19,20,21,22,23,24,25,
C                         26,27,28,29,30,31,32,33,34,35,36/
C          NGNX/4/,IGRP/7*1,12*2,10*3,7*4/
C          NGNX/5/,IGRP/11*1,2,2,3,3,4*4,2,2,6*3,4,4,7*5/
+          NGNX/1/,IGRP/36*1/
      DATA DES/10H REC-CONS ,10H REC-AGRI /,DEC/.9,.75,6*2.5E-3,
+     2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,2*1.E-4,13*2.5E-5/
C
C     THE ABOVE MATRICES AND ARRAYS ARE:
C     NOTE(6)   : HEADER LABEL FOR OUTPUT IDENTIFICATION.
C     TYM(9)    : NINE TIME STEPS AT WHICH INTRUDER IMPACTS
C                 ARE CALCULUATED.
C     DES(2)    : DESCRIPTION OF INTRUDER PATHWAYS.
C     IGRP(36)  : ARRAY USED TO DEFINE GROUPING OF WASTE STREAMS.
C     DEC(23,2) : DECON FACTORS FOR INCINERATOR AND CALCINER.
C
      READ(1,101)NSTR,NNUC,FICRP
      DO 10 I=1,NSTR
      READ(1,102)(BAS(I,J),J=1,27)
   10 READ(2,103)(ISPC(I,J),J=1,10)
      DO 20 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO 15 K=1,8
   15 READ(1,106)(DCF(I,J,K),J=1,7)
   20 CONTINUE
C
C     INPUT ENVIRONMENTAL PARAMETERS
C
      DO 25 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
+                   (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
+                   (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
+                   DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   25 CONTINUE
```

Listing for INTRUDE Computer Code (continued)

```
  101 FORMAT(2I5,7F5.2)
  102 FORMAT(A10,2E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3)
  103 FORMAT(10X,10I5)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4E10.3)
  106 FORMAT(10X,7E10.3)
C
      DO 35 ISTR=1,NSTR
      A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
      A2=BAS(ISTR,3) $ A3=A2/(A1*3.62) $ BAS(ISTR,3)=A3
      DO 30 I=5,27
   30 BAS(ISTR,I)=BAS(ISTR,I)*A1
      J=ISPC(ISTR,10)
      IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
      IH=J-IP*1000-IS*100-IL*10 $ IF(IL.EQ.0)GO TO 35
      IF(IP.LT.5)GO TO 35
      J=1 $ IF(IP.GT.5)J=2
      BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
      BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
   35 CONTINUE
C
C     NEXT LINE READS IN - THRU INPUT - THE 12 DISPOSAL
C     TECHNOLOGY INDICES AND HEADER INFORMATION.
C
      READ,IRDC $ READ 1002,NOTE $ WRITE(4,1003) NOTE,IRDC
      DO 70 IGNX=1,NGNX
      NX=0 $ VDIS=0. $ CALL ZERO(DZ,126)
C
C     DO 70 INTERPRETS IGRP(GROUPING) ARRAY
C     DO 50 IS THE MAIN LOOP IN CALCULATING INTRUDER IMPACTS
C     DO 45 LOOP DISTINGUISHES BETWEEN THE TIME STEPS
C
      DO 50 ISTR=1,NSTR
      IF(IGNX.NE.IGRP(ISTR))GO TO 50
      DO 45 ITYM=1,NTYM
      IRDC(12)=TYM(ITYM)+0.1 $ CALL RCLAIM(ISTR,NNUC)
      DO 40 I=1,7
      DO 40 J=1,2
   40 DZ(I,J,ITYM)=DZ(I,J,ITYM)+BAS(ISTR,3)*DZD(I,J)
   45 CONTINUE
      NX=1 $ VDIS=VDIS+BAS(ISTR,3)
   50 CONTINUE
      IF(NX.EQ.0)GO TO 70
      DO 55 I=1,NTYM
      DO 55 J=1,7
      DO 55 K=1,2
   55 DZ(J,K,I)=DZ(J,K,I)/VDIS
      IF(NGNX.EQ.36)WRITE(4,1004) BAS(IGNX,1)
      IF(NGNX.NE.36)WRITE(4,1005) IGNX
      DO 65 I=1,NTYM
      WRITE(4,1006) TYM(I)
      DO 65 K=1,2
      A1=0.
      DO 60 J=1,7
   60 A1=A1+DZ(J,K,I)*FICRP(J)
   65 WRITE(4,1007) DES(K),(DZ(J,K,I),J=1,7),A1
   70 CONTINUE
```

Listing for INTRUDE Computer Code (continued)

```
C
 1001 FORMAT(12I3)
 1002 FORMAT(6A10)
 1003 FORMAT(1H1/2X,6A10/2X*IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
+                         *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
+                         *IH =*I2*  ICL=*I2*  IPO=*I2* YEARS*I5)
 1004 FORMAT(//2X,A10)
 1005 FORMAT(//2X*GROUP NO =*I2)
 1006 FORMAT(/2X*YR =*F5.0*    BODY      BONE       LIVER*
+     *    THYROID    KIDNEY    LUNG    G-I TRACT   ICRP*)
 1007 FORMAT(2X,A10,8E10.3)
      STOP $ END
C
C
      SUBROUTINE RCLAIM(ISTR,NNUC)
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+           /DTIS/FSC(6),FSA(6)/IMPS/DZ(7,2)
      DIMENSION EMP(3),DMY(7,5)
      DATA EMP/.5,.75,.5/
C
C     EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
C     DMY(7,5)  : MATRIX TO HOLD 5 SUB-PATHWAYS WHICH WILL LATER
C                 BE ADDED TOGETHER TO DEFINE CONSTRUCTION AND%
C                 AGRICULTURE PATHWAYS.
C
   10 I5=ISPC(ISTR,5) $ I7=ISPC(ISTR,7) $ I9=ISPC(ISTR,9)
      I6=ISPC(ISTR,6) $ FDES=EMP(IE)*(1.-0.9*IG)
      I8=ISPC(ISTR,8)
      A8=1. $ IF(I6.EQ.2.OR.I6.EQ.3)A8=0.8
      IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
C
C     GDEL DEFINES YEAR OF SCENARIO INITIATION
C
      GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      IF(I9.EQ.3) A8=A8*10.
      A5=1. $ IF(I5.LT.3)A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
      I12=1
      IF(IL.EQ.0.AND.IS.EQ.1.AND.I8.EQ.1) I12=2
      IF(IL.EQ.1.AND.IS.EQ.0) I12=3
      IF(IL.EQ.1.AND.IS.EQ.1.AND.I8.EQ.1) I12=4
      IF(IH.EQ.1.OR.ID.EQ.2) I12=5
      GO TO (11,12,13,14,15),I12
   11 A4C=1. $ A4A=1. $ A8C=A8 $ A8A=A8 $ GO TO 20
   12 A4C=0.012 $ A4A=0. $ A8C=0.012*A8 $ A8A=0. $ GO TO 20
   13 A4C=0.1 $ A4A=0. $ A8C=A8/1200. $ A8A=0. $ GO TO 20
   14 A4C=0.0012 $ A4A=0. $ A8C=0.0012*A8/1200. $ A8A=0. $ GO TO 20
   15 A4C=0.01 $ A4A=0. $ A8C=0.1*A8/1.44E+6 $ A8A=0.
      IF(IG.EQ.0) A8C=A8C*0.1
   20 CONTINUE
      CALL ZERO(DZ,14) $ WRITE(3,101) BAS(ISTR,1),BAS(ISTR,3),ISTR
 —101 FORMAT(/2X,A10,E10.3,I5)
C
```

Listing for INTRUDE Computer Code (continued)

```
C     MAIN LOOP IN CALCULATING DOSES FROM ALL NUCLIDES FOR
C     SEVEN ORGANS.
C
      DO 40 INUC=1,NNUC
      A1=A9*FDES*FXM(AL(INUC)*GDEL)*BAS(ISTR,INUC+4)
      DO 30 I=1,7
      A2=DCF(INUC,I,5)
      DMY(I,1)=A1*0.057*A2*A8C $ DMY(I,3)=A1*0.27*A2*0.25*A8A
      DMY(I,2)=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
      DMY(I,4)=A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)*0.25
      DMY(I,5)=0.25*0.5*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
C     DMY(I,2)=A1*A4C*FSC(IR)*DCF(INUC,I,2)
C     DMY(I,4)=A1*A4A*FSA(IR)*DCF(INUC,I,3)*0.25
C     DMY(I,5)=0.25*0.5*A1*A4A*DCF(INUC,I,4)*FMF(INUC)
      DZ(I,1)=DZ(I,1)+DMY(I,1)+DMY(I,2)
      DZ(I,2)=DZ(I,2)+DMY(I,3)+DMY(I,4)+DMY(I,5)
   30 CONTINUE
      IF(ISTR.LT.30)GO TO 40
C     WRITE(3,102) NUC(INUC),((DMY(I,J),I=1,7),J=1,5)
  102 FORMAT(2X,A10,7E9.2/(12X,7E9.2))
   40 CONTINUE
      RETURN $ END
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
      FUNCTION FXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      FXM=A2
      RETURN $ END
```

Listing for GRWATER Computer Code

```
      PROGRAM GRWATER(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
C
C     TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
C       FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCK.
C     TAPE2 CONTAINS THE SPECTRAL (ISPC) FILE.
C     INPUT IS USED TO READ IRDC - DISPOSAL TECHNOLOGY INDICES.
C     TAPE3 CONTAINS DETAILED OUTPUT - FROM SUBROUTINE GWATER.
C     TAPE4 CONTAINS THE MAIN PROGRAM OUTPUT (GROUNDWATER IMPACTS).
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IRDC(12)
+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
+           RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRFT(6)
+           /IMPS/DZD(23,18,21)/DHIC/IHIC(36),THIC
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DTNX BLOCK CONTAINS DISPOSAL TECHNOLGY INDICES.
C     IMPS BLOCK  - DZD(23,18,21) - WILL CONTAIN RESULTS OF GWATER
C     - DOSES FOR 23 NUCLIDES, 18 TIME STEPS, 7 ORGAN FOR 3 LOCATIONS.
C     DHIC BLOCK CONCERNS THE USE OF HIGH INTEGRITY CONTAINERS:
C     IHIC INDICATES WHICH STREAMS USE HIGH INTEGRITY CONTAINERS
C     AND THIC IS TIME ATTRIBUTE ASSOCIATED WITH CONTAINER.
C
      DIMENSION TIMP(6),TYM(18),DES(3),DZ(7,3,18),NDX(36)
      DATA NDX/36*1/
      DATA IHIC/36*0/,THIC/100./
      DATA TYM/40.,50.,60.,100.,200.,300.,400.,500.,600.,700.,
+     800.,900.,1000.,2000.,4000.,6000.,8000.,10000./,NTYM/18/
      DATA DES/10H REC-WELL ,10H POP-WELL ,10H POP-SURF /
C
C        NDX(36)     : INDEX TO INCLUDE OR EXCLUDE PARTICULAR
C                      STREAMS IN ANAYSIS (1=INCLUDE, 0=EXCLUDE).
C        TYM(18)     : 18 TIME STEPS TO BE CONSIDERED IN GROUNDWATER
C                      ANALYSIS.
C        DES(3)      : DESCRIPTION OF 3 PATHWAYS OF CONCERN.
C        DZ(7,3,18)  : DOSES SUMMED OVER ALL NUCLIDES.
C
      READ,IRDC $ READ 1002,TIMP $ WRITE(4,1003) TIMP,IRDC
      CALL COMBYN(NSTR,NNUC)
      VNOT=0. $ VREG=0. $ VLAY=0. $ VHOT=0.
C
C     LOOP 30 CLASSIFIES WASTE STREAMS AND ACCUMULATES THEIR
C     VOLUME AS NOT ACCEPTABLE, REGULAR, LAYERED, OR HOT.
C
      DO 30 ISTR=1,NSTR
      IF(IRDC(1).EQ.4) ISPC(ISTR,5)=ISPC(ISTR,5)-1
      IMOD=1 $ CALL RCLAIM(ISTR,NNUC,IMOD)
      IF(NDX(ISTR).NE.1)ISPC(ISTR,11)=0
      II=ISPC(ISTR,11)+1 $ GO TO(10,15,20,25),II
   10 VNOT=VNOT+BAS(ISTR,3) $ GO TO 30
   15 VREG=VREG+BAS(ISTR,3) $ GO TO 30
   20 VLAY=VLAY+BAS(ISTR,3) $ GO TO 30
   25 VHOT=VHOT+BAS(ISTR,3)
   30 CONTINUE
      WRITE(4,1004) VREG,VLAY,VHOT,VNOT
C
```

Listing for GRWATER Computer Code (continued)

```
      CALL GWATER(NSTR,NNUC,NTYM,TYM) $ CALL ZERO(DZ,378)
C
C     LOOP 40 SUMS DOSES OVER ALL NUCLIDES
C
      DO 40 ITYM=1,NTYM
      DO 40 K=1,3
      KK=(K-1)*7
      DO 40 J=1,7
      DO 40 INUC=1,NNUC
   40 DZ(J,K,ITYM)=DZ(J,K,ITYM)+DZD(INUC,ITYM,KK+J)
C
C     LOOP 70 OUTPUTS GROUNDWATER DOSES FOR 7 ORGANS, 3 PATHWAYS,
C     AND 18 TIMES.
C
      DO 70 ITYM=1,NTYM
      TYMD=TYM(ITYM) $ WRITE(4,1005) TYMD
      DO 60 K=1,3
      A1=0.
      DO 50 J=1,7
   50 A1=A1+DZ(J,K,ITYM)*FICRP(J)
   60 WRITE(4,1006) DES(K),(DZ(J,K,ITYM),J=1,7),A1
   70 CONTINUE
C
C     LOOP 80 OUTPUTS DOSES FOR EACH TIME CONSIDERED FOR EACH NUCLIDE
C
      DO 80 INUC=1,12
      WRITE(4,1007) NUC(INUC)
      DO 80 ITYM=1,NTYM
      DO 80 K=1,3
      KK=(K-1)*7
   80 WRITE(4,1008) TYM(ITYM),DES(K),(DZD(INUC,ITYM,KK+J),J=1,7)
C
 1001 FORMAT(12I3)
 1002 FORMAT(6A10)
 1003 FORMAT(2X,6A10/2X*IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
+                          *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
+                          *IH =*I2*  ICL=*I2*  IPO=*I2* YEARS*I5)
 1004 FORMAT(2X*VREG =*E9.2* VLAY =*E9.2* VHOT =*E9.2* VNOT =*E9.2)
 1005 FORMAT(/2X*YR =*F5.0*    BODY       BONE       LIVER*
+     *    THYROID    KIDNEY    LUNG    G-I TRACT   ICRP*)
 1006 FORMAT(2X,A10,8E10.3)
 1007 FORMAT(/2X,A10,10X*BODY       BONE       LIVER*
+     *    THYROID    KIDNEY    LUNG    G-I TRACT*)
 1008 FORMAT(2X,F6.0,2X,A10,7E10.3)
      STOP $ END
C
C
      SUBROUTINE COMBYN(NSTR,NNUC)
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+          /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTIS/FSC(6),FSA(6),
+          PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),
+          DTPC(6),TPO(6,2),NRET(6)
      DIMENSION DEC(23,2)
      DATA DEC/.9,.75,6*2.5E-3,2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,
+     2*1.E-4,13*2.5E-5/
```

DF 422

Listing for GRWATER Computer Code (continued)

```
      READ(1,101)NSTR,NNUC,FICRP
      DO 70 I=1,NSTR
      READ(1,102)(BAS(I,J),J=1,27)
      READ(2,103)(ISPC(I,J),J=1,10)
   70 CONTINUE
      DO 80 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO 75 K=1,8
      READ(1,106)(DCF(I,J,K),J=1,7)
   75 CONTINUE
   80 CONTINUE
      DO 90 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
+     (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),(RGF(I,J),J=1,3),(POP(I,J),J=1,3)
+     NRET(I),DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   90 CONTINUE
  101 FORMAT(2I5,7F5.2)
  102 FORMAT(A10,2E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3)
  103 FORMAT(10X,10I5)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6F10.3,I5/10X,4F10.3)
  106 FORMAT(10X,7E10.3)
      DO 50 ISTR=1,NSTR
      A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
      A2=BAS(ISTR,3) $ A3=A2/(A1*3.62) $ BAS(ISTR,3)=A3
      DO 20 I=5,27
   20 BAS(ISTR,I)=BAS(ISTR,I)*A1
      J=ISPC(ISTR,10)
      IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
      IH=J-IP*1000-IS*100-IL*10 $ IF(IL.EQ.0)GO TO 50
      IF(IP.LT.5)GO TO 50
      J=1 $ IF(IP.GT.5)J=2
      BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
      BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
   50 CONTINUE
      DO 60 INUC=1,NNUC
      A2=RET(INUC,4) $ A1=(A2/RET(INUC,1))**0.334
      RET(INUC,5)=A2*A1 $ RET(INUC,3)=A2/A1
   60 RET(INUC,2)=RET(INUC,1)*A1
      RETURN $ END
C
C
      SUBROUTINE RCLAIM(ISTR,NNUC,IMOD)
C
C     THIS SUBROUTINE IS USED TO CLASSIFY EACH WASTE STREAM AS:
C          (1) NOT ACCEPTABLE, (2) REGULAR,
C          (3) LAYERED, OR (4) HOT
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+           /DTIS/FSC(6),FSA(6)/IMPS/D7(7,2)/DHIC/IHIC(36),THIC
C
C     D7(7,2) : INTRUDER DOSES USED IN CLASSIFICATION TESTS
C
```

<u>Listing for GRWATER Computer Code</u> (continued)

```
      DIMENSION EMP(5),DLC(7)
      DATA EMP/.5,.75,.5,.5,.75/,DLC/500.,500.,1500.,3000.,3*1500./
C
C     EMP(5) : VOLUME EMPLACEMENT EFFICIENCIES
C     DLC(7) : DOSE LIMITING CRITERIA FOR 7 ORGANS
C
      I5=ISPC(ISTR,5) $ I6=ISPC(ISTR,6) $ I7=ISPC(ISTR,7)
      I8=ISPC(ISTR,8) $ I9=ISPC(ISTR,9)
      IF(IHIC(ISTR).GT.0) I8=1
      A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
      IF(I7.EQ.1.OR.IS.EQ.0) I6=I6-1
      FDES=EMP(IE)*(1.-.9*IG)
      IF(I9.EQ.3) A7=A7*10.
      A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
      A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
      I3=1 $ IF(IS.EQ.1.AND.I8.EQ.1)I3=2
      IF(ID.EQ.2)I3=2
C
C     TESTING ROUTINE FOR CLASSIFING WASTE. BASED ON INTRUDER
C     CONSTRUCTION AND AGRICULTURE PATHWAYS.
C
   10 GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
      CALL ZERO(D7,14) $ GO TO (11,12,13,14,15,16,17,18),I3
   11 A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   12 A4C=0.012 $ A4A=0. $ A8C=0.012*A7 $ A8A=0. $ GO TO 20
   13 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   14 A4C=0.1 $ A4A=0. $ A8C=A7/1200. $ A8A=0. $ GO TO 20
   15 A4C=0.0012 $ A4A=0. $ A8C=0.0012*A7/1200. $ A8A=0. $ GO TO 20
   16 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   17 A8C=0.1*A7/1.44E6 $ IF(IG.EQ.0)A8C=A8C*0.1
      A4C=0.01 $ A4A=0. $ A8A=0. $ GO TO 20
   18 GDEL=IPO+1000. $ A8C=A7 $ IF(IG.EQ.0)A8C=0.1*A7
      A4C=1. $ A4A=1. $ A8A=A8C
C
C     MAIN LOOP FOR CALCULATING DOSES
C
   20 DO 40 INUC=1,NNUC
      A1=A9*FDES*FXM(AL(INUC)*GDEL)*RAS(ISTR,INUC+4)
      DO 30 I=1,7
      A2=DCF(INUC,I,5)
      B1=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
      B2=A1*A8C*A2*0.057
      B3=0.25*A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)
      B4=0.5*0.25*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
C     B1=A1*A4C*FSC(IR)*DCF(INUC,I,2)
C     B3=0.25*A1*A4A*FSA(IR)*DCF(INUC,I,3)
C     B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)*FMF(INUC)
      B5=0.25*A1*A8A*A2*0.27
      D7(I,1)=D7(I,1)+B1+B2
   30 D7(I,2)=D7(I,2)+B3+B4+B5
   40 CONTINUE
C
```

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Listing for GRWATER Computer Code (continued)

```
C          TEST DOSES AGAINST DLC
C
           DO 50 IORG=1,7
           DO 50 IPTH=1,2
           IF(DZ(IORG,IPTH).GT.DLC(IORG)) GO TO 60
       50  CONTINUE
           GO TO (51,52,51,53,53,54,55,56),I3
       51  ISPC(ISTR,11)=1 $ RETURN
       52  I3=3 $ GO TO 10
       53  I3=6 $ GO TO 10
       54  ISPC(ISTR,11)=2 $ RETURN
       55  I3=8 $ GO TO 10
       56  ISPC(ISTR,11)=3 $ RETURN
       60  GO TO (61,62,63,63,63,63,70,70),I3
       61  IF(IL.EQ.0)GO TO 63
           I3=4 $ GO TO 10
       62  IF(IL.EQ.0)GO TO 63
           I3=5 $ GO TO 10
       63  IF(IH.EQ.0)GO TO 70
           I3=7 $ GO TO 10
       70  ISPC(ISTR,11)=0
C
C          ISPC(ISTR,11) CONTAINS WASTE CLASSIFICATION INDEX
           RETURN $ END
C
           FUNCTION ERFS(A1,A2)
           A3=0.5*SQRT(A2/A1)
           A4=A3*(1.-A1) $ A5=A3*(1.+A1)
           IF(A4.GT.0)GO TO 10
           ERFS=2.+EXM(A4*A4)*(POLY(A5)-POLY(-A4)) $ RETURN
       10  ERFS=EXM(A4*A4)*(POLY(A4)+POLY(A5))
           RETURN $ END
C
C
           FUNCTION POLY(X1)
           DATA A1,A2,A3,A4,A5,P/.254829592,-.284496736,1.421413741,
+                                    -1.453152027,1.061405429,.3275911/
           T1=1./(1.+P*X1)
           POLY=T1*(A1+T1*(A2+T1*(A3+T1*(A4+T1*A5))))
           RETURN $ END
           FUNCTION EXM(A1)
           A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
           EXM=A2
           RETURN $ END
C
C
           SUBROUTINE GWATER(NSTR,NNUC,NTYM,TYMD)
           COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+                /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+                /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+                /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
+                TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+                /IMPS/DZ(23,18,21)/DHIC/IHIC(36),THIC
           DIMENSION EMP(5),EFF(2),SEFF(2),DMY(3,20),TYMD(18),RES(18,3)
           DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,SEFF/0.9,0.35/,NOPT/1/
           TVOL=0. $ GINS=IPO+IIC $ NSEC=10 $ CALL ZERO(DZ,8694)
```

Listing for GRWATER Computer Code (continued)

```
C
C     NEXT SECTION DETERMINES PERCOLATION VALUE AND
C     LOWER LIMIT FOR THE DILUTION FACTOR
C
      PRC1=PRC(IR,1) $ PRC2=PRC(IR,2)
      IF(IG.EQ.1.OR.ID.EQ.2) GO TO 5
      IF(IE.GT.3) PRC1=PRC(IR,1)/10.
      IF(IE.GT.3) PRC2=PRC(IR,2)/10.
    5 CONTINUE
      IF(IC.EQ.1)PRCD=PRC1
      IF(IC.GT.1)PRCD=PRC2
      IF(IX.EQ.1)PRCD=4.*PRC1
      IF(IC.EQ.1.AND.IX.EQ.2) PRCD=2.25*PRC1
      IF(IC.EQ.2.AND.IX.EQ.2) PRCD=4.0*PRC2
      TVOL=352000.*SQRT(PRC(IR,1)*27.8)
      IF(TVOL.LT.7700.) TVOL=7700.
C
C     MAIN LOOP OF GROUNDWATER PATHWAY EQUATION
C          ************************************
C          SOME OF THE MAIN VARIABLE NAMES ARE:
C          PERC  : SOURCE TERMS
C          PER2
C          FMF   : RADIONUCLIDE PARTITION RATIOS
C          QFC   : DILUTION FACTOR
C          TDUR  : DURATION TIME OF RADIONUCLIDE
C          RES   : MIGRATION REDUCTION FACTOR
C          RGF   : GEOMETRICAL REDUCTION FACTOR
C          *************************************
C
      DO 90 ISTR=1,NSTR
      I11=ISPC(ISTR,11) $ IF(I11.EQ.0)GO TO 90
      WRITE(3,101) BAS(ISTR,1),BAS(ISTR,3),ISTR,I11
      I6=ISPC(ISTR,6) $ VUR=0.9/(EMP(IE)*FFF(ID))
      I7=ISPC(ISTR,7) $ IF(I11.EQ.3)VUR=0.19
      I8=ISPC(ISTR,8) $ IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
      I9=ISPC(ISTR,9) $ GDEL=0. $ IF(IHIC(ISTR).EQ.1)GDEL=THIC
      IF(IHIC(ISTR).GT.0) I8=1
      PERC=PRCD $ IF(I8.NE.1.OR.IS.NE.1)GO TO 10
      IF(IC.EQ.1)PERC=PRC1
      IF(IC.GT.1)PERC=PRC2
   10 IF(I11.EQ.3.OR.ID.EQ.2)PERC=PRC2/16.
      PERC=PERC*(1.0-0.9*IG) $ PER2=3.6*PERC+0.1*PRC1
      IF(ID.EQ.2)PER2=0.9*PERC+0.1*PRC2
      NX=0 $ IF(PERC.LT.PRC1)NX=1
      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
      I1=NRET(IR) $ IF(IS.EQ.0.OR.I7.EQ.1)I1=I1-1
      TDUM=1.0/(PERC*VUR*A6*A9) $ IF(I1.LE.0)I1=1
      DO 80 INUC=1,12
      IF(BAS(ISTR,INUC+4).LT.1.E-14)GO TO 80
      TDUR=TDUM/FMF(INUC) $ CALL ZERO(DMY,60)
      C1=TDUR $ IF(NX.EQ.0.OR.NOPT.EQ.0)GO TO 15
      IF(C1.LT.GINS)C1=GINS
C
```

Listing for GRWATER Computer Code (continued)

```
C     SUBROUTINE RTIJ CALCULATES THE MIGRATION REDUCTION FACTOR
C     RESULTS ARE RETURNED IN RES MATRIX.
C
   15 CALL RTIJ(TYMD,NTYM,INUC,IR,I1,C1,0.,RES,GDFL)
      B1=BAS(ISTR,3)*BAS(ISTR,INUC+4)/TDUR
      DO 30 IPTH=1,3
      B2=B1*RGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC)
      IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
      I3=(IPTH-1)*7 $ I2=6 $ IF(IPTH.EQ.3)I2=7
      DO 25 ITYM=1,NTYM
      A3=EXM(AL(INUC)*TYMD(ITYM))
      DO 20 I=1,7
      A4=A3*RES(ITYM,IPTH)*B2*DCF(INUC,I,I2)
      DMY(IPTH,ITYM)=DMY(IPTH,ITYM)+A4*FICRP(I)
   20 DZ(INUC,ITYM,I3+I)=DZ(INUC,ITYM,I3+I)+A4
   25 CONTINUE
   30 CONTINUE
C
C     THE NEXT SECTION CONSIDERS (OPTIONAL BY NOPT) THE SECOND
C     SOURCE TERM OF A 2-STEP ANALYSIS WITH AN INCREASED SOURCE
C     TERM (PER2) AFTER THE INSTITTUTIONAL CONTROL PERIOD.
C
      IF(NX.EQ.0.OR.NOPT.EQ.0)GO TO 60
      IF(TDUR.LE.GINS)GO TO 60
      T1=GINS $ T2=T1+PERC*(TDUR-T1)/PER2
      CALL RTIJ(TYMD,NTYM,INUC,IR,I1,T2,T1,RES,GDFL)
      B1=B1*PER2/PERC
      DO 50 IPTH=1,3
      B2=B1*RGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC)
      IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
      I3=(IPTH-1)*7 $ I2=6 $ IF(IPTH.EQ.3)I2=7
      DO 45 ITYM=1,NTYM
      A3=EXM(AL(INUC)*TYMD(ITYM))
      DO 40 I=1,7
      A4=A3*RES(ITYM,IPTH)*B2*DCF(INUC,I,I2)
      DMY(IPTH,ITYM)=DMY(IPTH,ITYM)+A4*FICRP(I)
   40 DZ(INUC,ITYM,I3+I)=DZ(INUC,ITYM,I3+I)+A4
   45 CONTINUE
   50 CONTINUE
   60 WRITE(3,102) NUC(INUC)
      WRITE(3,103) ((DMY(I,J),J=1,NTYM),I=1,3)
   80 CONTINUE
   90 CONTINUE
C
C     END OF MAIN LOOP
C
  101 FORMAT(2X,A10,F10.3,2I5)
  102 FORMAT(2X,A7)
  103 FORMAT(9X,9F9.2)
      RETURN $ END
C
C
      SUBROUTINE RTIJ(TYMD,NTYM,INUC,IR,I1,TDUR,TMIN,RES,GDFL)
      COMMON/NUCS/NUC(23),AL(23),EMF(23),RET(23,5)
     +      /DTIS/FSCA(42),TTM(6,3),TPC(6,3),RGFP(36),DTTM(6),DTPC(6)
      DIMENSION TYMD(NTYM),RES(18,3),RTTM(6),RTPC(6)
```

Listing for GRWATER Computer Code (continued)

```
      DATA BTTM/350.,66.,175.,283.,56.,116./,
     +     BPTC/700.,1900.,700.,1600.,1900.,1900./,NOPTW/0/
C
C     NOPTW=0 SIGNIFIES INTRUDER WELL
C     NOPTW=1 SIGNIFIES BOUNDARY WELL (BTTM,BTPC)
C
      CALL ZERO(RES,54)
      DO 30 IPTH=1,3
      A1=RET(INUC,I1)*TTM(IR,IPTH)+GDEL
      IF(IPTH.EQ.1.AND.NOPTW.EQ.1) A1=RET(INUC,I1)*BTTM(IR)+GDEL
      DO 20 ITYM=1,NTYM
      TYM=TYMD(ITYM)-TMIN $ A2=TYMD(ITYM)-TDUR
      DO 10 ISEC=1,10
      B3=1.0/(A1+RET(INUC,I1)*(ISEC-1)*DTTM(IR))
      IF(TYM*1.1*B3.LT.1.0) GO TO 20
      B4=TPC(IR,IPTH)+(ISEC-1)*DTPC(IR)
      IF(IPTH.EQ.1.AND.NOPTW.EQ.1) B4=BTPC(IR)+(ISEC-1)*DTPC(IR)
      A3=0.5*ERFS(B3*TYM,B4)
      IF(A2.GT.0.)A3=A3-0.5*ERFS(B3*A2,B4)
      IF(A3.LT.0.)A3=0.
   10 RES(ITYM,IPTH)=RES(ITYM,IPTH)+A3
   20 CONTINUE
   30 CONTINUE
      RETURN $ END
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
```

Listing for OPTIONS Computer Code

```
      PROGRAM OPTIONS(INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4)
C
C     TAPE1 CONTAINS NSTR(NUMBER OF STREAMS), NNUC(NUMBER OF NUCLIDES),
C     FICRP(ICRP FACTORS), BAS AND DCF MATRICES AND DTIS BLOCKS.
C     TAPE2 CONTAINS ISPC(SPECTRAL) FILE.
C     TAPE3 READS IN THE DISPOSAL TECHNOLOGY CASES
C     TAPE4 CONTAINS PROGRAM OUTPUT.
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
     +        /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTNX/IRDC(12)
     +        /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
     +             RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
     +        /VOL/VREG,VLAY,VHOT
     +        /IMPS/DZ(8,7,2),DZQ(4,7,2),DZA(7,7),DZS(36,7,2)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DTNX BLOCK CONTAINS THE DISPOSAL TECHNOLOGY INDICES.
C     VOL BLOCK CONTAINS TOTAL REGULAR, LAYERED, AND HOT WASTE VOLUMES.
C     IMPS IS EXPLAINED BELOW:
C     DZ(8,7,2)   = OUTPUT FROM SURROUTINE RCLAIM TO MAIN PROGRAM
C                   CONTAINING INTRUDER IMPACTS FOR SEVEN ORGANS
C                   AND TWO PATHWAYS UNDER EIGHT TESTING CONDITIONS.
C     DZQ(4,7,2) = THIS MATRIX IS USED TO VOLUME AVERAGE THE OUTPUT
C                   DOSES FROM RCLAIM. FINAL VALUES ARE FOR SEVEN ORGANS
C                   AND TWO PATHWAYS AT THREE TIME STEPS (IIC, 500,
C                   1000 YEARS) AND SUBSEQUENTLY PRINTED OUT TO TAPE4.
C     DZA(7,7)    = OUTPUT FROM SUBROUTINE ACCEXP TO MAIN PROGRAM
C                   CONTAINING THE ACCIDENT AND EXPOSURE DOSES FOR
C                   SEVEN ORGAN AND SEVEN PATHWAYS.
C     DZS(36,7,2) = OUTPUT FROM SUBROUTINE ACCEXP FOR THE TWO
C                    ACCIDENT PATHWAYS CONSIDERED BY ALL STREAMS (36)
C                    AND 7 ORGANS.
      DIMENSION IQR(36),IQL(36),IQH(36),IQN(36),G(4),D(4)
      DIMENSION NOTE(6),DES(9),TIMP(6),COST(5),UN(5),NDX(36)
C
C     THESE ARRAYS ARE EXPLAINED BELOW:
C     IQR(36), IQL(36) = INDICES OF STREAMS BELONGING TO EACH
C     IQH(36), IQN(36)   OF THE FOUR WASTE TYPES (REGULAR, LAYERED,
C                        HOT, AND NOT ACCEPTABLE)
C     NOTE(6)          = HEADER INFORMATION READ IN THRU INPUT AND
C                        PRINTED OUT ON TOP OF OUTPUT FOR IDENTIFICATION.
C     DES(9)           = DESCRIPTION OF 9 PATHWAYS CONSIDERED.
C     TIMP(6)          = TRANSPORTATION IMPACTS CALCULATED IN SUBROUTINE
C                       TRANSP AND PASSED TO MAIN PROGRAM.
C     COST(5)          = DISPOSAL IMPACTS CALCULATED IN SUBROUTINE ECON.
C     G(4),D(4)        = LOCAL ARRAYS WHICH ACCUMULATES PROCESSING IMPACTS.
C                        G FOR PROCESSING AT GENERATOR AND D FOR PROCESSING
C                        AT THE DISPOSAL SITE
C     UN(5)            = UNIT COSTS ($/M3) FOR PROCESSING, TRANSPORTATION,
C                        DISPOSAL DURING OPERATIONAL PERIOD, AND DISPOSAL
C                        DURING POST CLOSURE PERIOD.
C     NDX              = STREAM CONTROL ARRAY
C                          0 = DELETE STREAM FROM CONSIDERATION
C                          1 = PROCEED AS NORMAL
C                          2 = HIGH INTEGRITY CONTAINER
C                          3 = STABLIZED
```

```
C
      DATA DES/10H REC-CONS ,10H REC-AGRI ,
+               10H REC-AIR  ,10H ERO-AIR  ,10H REC-WAT  ,
+               10H ERO-WAT  ,10H ACC-SNGC ,10H ACC-FIRE ,10H ACC-AVG  /
      DATA RI,RJ/.1,.09/
      DATA NDX/36*1/
C
C     SUBROUTINE COMBYN READS IN MOST OF THE INPUT DATA
C     AND CALCULATES THE PROCESSING IMPACTS. PROCESSING IMPACTS
C     ARE RETURNED IN BAS(ISTR,29) THRU BAS(ISTR,32).
C
      CALL COMBYN(NSTR,NNUC,NDX)
C
      READ(3,)NCASE
      DO 300 NC=1,NCASE
      READ(3,1002)NOTE $ READ(3,)IRDC
      WRITE(4,1003)NOTE,IRDC
      CALL ZERO(DZ,721)
      VREG=0. $ VLAY=0. $ VHOT=0. $ VNOT=0.
      NREG=0  $ NLAY=0  $ NHOT=0  $ NNOT=0
C
C
C     NEXT SECTION CALCULATES THE INTRUDER IMPACTS AND DETERMINES
C     THE WASTE STREAM STATUS - ISPC(ISTR,11).
C
C
      DO 50 ISTR=1,NSTR
      IF(IRDC(1).EQ.4) ISPC(ISTR,5)=ISPC(ISTR,5)-1
      IDX=NDX(ISTR) $ IMOD=1 $ CALL RCLAIM(ISTR,NNUC,IMOD,IDX)
      II=ISPC(ISTR,11)+1 $ GO TO (10,20,30,40),II
   10 NNOT=NNOT+1             $ ION(NNOT)=ISTR
      VNOT=VNOT+BAS(ISTR,3) $ GO TO 50
   20 NREG=NREG+1             $ IOR(NREG)=ISTR
      DO 25 I=1,7
      DO 25 J=1,2
      DZQ(1,I,J)=DZQ(1,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
      DZQ(2,I,J)=DZQ(2,I,J)+BAS(ISTR,3)*DZ(3,I,J)
   25 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
      VREG=VREG+BAS(ISTR,3) $ GO TO 50
   30 NLAY=NLAY+1             $ IOL(NLAY)=ISTR
      DO 35 I=1,7
      DO 35 J=1,2
      DZQ(4,I,J)=DZQ(4,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
      DZQ(2,I,J)=DZQ(2,I,J)+BAS(ISTR,3)*DZ(3,I,J)
   35 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
      VLAY=VLAY+BAS(ISTR,3) $ GO TO 50
   40 NHOT=NHOT+1             $ IOH(NHOT)=ISTR
      DO 45 I=1,7
      DO 45 J=1,2
      DZQ(1,I,J)=DZQ(1,I,J)+BAS(ISTR,3)*DZ(IMOD,I,J)
   45 DZQ(3,I,J)=DZQ(3,I,J)+BAS(ISTR,3)*DZ(8,I,J)
      VHOT=VHOT+BAS(ISTR,3)
   50 CONTINUE
      IF(VLAY.EQ.0.) VLAY=1.
```

Listing for OPTIONS Computer Code (continued)

```
      DO 55 J=1,7
      DO 55 K=1,2
      DZQ(1,J,K)=DZQ(I,J,K)/(VREG+VHOT)
      IF(VLAY.GT.1.) DZQ(1,J,K)=DZQ(1,J,K)+DZQ(4,J,K)/VLAY
      DZQ(2,J,K)=DZQ(2,J,K)/(VREG+VLAY)
   55 DZQ(3,J,K)=DZQ(3,J,K)/(VREG+VLAY+VHOT)
C
C     THE MATRIX DZQ NOW CONTAINS THE VOLUME AVERAGED INTRUDER IMPACTS.
C
      IF(VLAY.EQ.1.) VLAY=0.
      IF(NREG.GT.0) CALL PRT(VREG,IQR,NREG,1,NDX)
      IF(NLAY.GT.0) CALL PRT(VLAY,IQL,NLAY,2,NDX)
      IF(NHOT.GT.0) CALL PRT(VHOT,IQH,NHOT,3,NDX)
      IF(NNOT.GT.0) CALL PRT(VNOT,IQN,NNOT,4,NDX)
      WRITE(4,1008)
      DO 70 I=1,3
      DO 65 K=1,2
      A1=0.
      DO 60 J=1,7
   60 A1=A1+DZQ(I,J,K)*FICRP(J)
   65 WRITE(4,1009) DES(K),(DZQ(I,J,K),J=1,7),A1
   70 CONTINUE
C
C     NEXT SECTION CALCULATES THE DOSES FOR THE ACCIDENT AND EXPOSURE
C     SCENARIOS - CONSISTS OF SEVEN PATHWAYS FOR SEVEN ORGANS.
C
      CALL ACCEXP(NSTR,NNUC,NDX)
      WRITE(4,1014)
      DO 100 K=1,7
      KK=K+2 $ A1=0.
      DO 95 J=1,7
   95 A1=A1+DZA(J,K)*FICRP(J)
  100 WRITE(4,1015)DES(KK),(DZA(J,K),J=1,7),A1
C
C     NEXT SECTION CALCULATES THE TRANSPORTATION IMPACTS AND THE
C     DISPOSAL IMPACTS THRU SURROUTINES TRANSP AND ECON, RESPECTIVELY.
C
      CALL TRANSP(TIMP,NSTR)
      CALL ZERO(G,4) $ CALL ZERO(D,4)
      DO 110 I=1,NSTR
      I1=ISPC(I,10) $ I2=I1/100
      I3=(I1/10)-I2*10 $ IF(I3.EQ.0) GO TO 110
C
C     SEPERATE GENERATOR AND DISPOSAL PROCESSING IMPACTS
C
      IF(I3.EQ.2) GO TO 105
      G(1)=G(1)+BAS(I,29) $ G(2)=G(2)+BAS(I,30)
      G(3)=G(3)+BAS(I,31) $ G(4)=G(4)+BAS(I,32)
      GO TO 110
  105 D(1)=D(1)+BAS(I,29) $ D(2)=D(2)+BAS(I,30)
      D(3)=D(3)+BAS(I,31) $ D(4)=D(4)+BAS(I,32)
  110 CONTINUE
C
      CALL ECON(NSTR,RI,RJ,COST,NDX)
C
```

Listing for OPTIONS Computer Code (continued)

```
C
C     PROCESSING, TRANSPORTATION, AND DISPOSAL IMPACTS ARE NOW BROUGHT
C     TOGETHER AND PRINTED OUT.
C
      VT=VREG+VLAY+VHOT
      UN(1)=G(1)/VT $ UN(2)=D(1)/VT
      UN(3)=TIMP(1)/VT $ UN(4)=COST(1)/VT $ UN(5)=COST(5)/VT
      COST(2)=COST(2)+TIMP(5) $ X=0.
      TIMP(3)=TIMP(3)+TIMP(6)
      WRITE(4,1013)RI,RJ,G(1),D(1),TIMP(1),COST(1),COST(5),
+     UN(1),UN(2),UN(3),UN(4),UN(5),G(4),D(4),TIMP(4),X,
+     G(3),D(3),TIMP(3),COST(2),X,X,X,COST(4),G(2),D(2),TIMP(2),COST(3)
C
      DO 120 K=1,2
      IF(K.EQ.1)WRITE(4,1016)
      IF(K.EQ.2)WRITE(4,1017)
      WRITE(4,1018)
      DO 120 I=1,NSTR
      A1=0.
      DO 115 J=1,7
  115 A1=A1+DZS(I,J,K)*FICRP(J)
      WRITE(4,1020)BAS(I,1),(DZS(I,J,K),J=1,7),A1
  120 CONTINUE
  300 CONTINUE
 1001 FORMAT(12I3)
 1002 FORMAT(6A10)
 1003 FORMAT(1H1/2X,6A10//2X*DISPOSAL TECHNOLOGY INDICES*/2X,
+                         *IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
+                         *IF =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
+                         *IH =*I2*  ICL=*I2*  IPO=*I2*  IIC=*I4)
 1008 FORMAT(1H1/2X,*INTRUDER IMPACTS*,7X,*BODY       BONE       LIVER*
+     *    THYROID    KIDNEY     LUNG     G-I TRACT    ICRP*)
 1009 FORMAT(12X,A10,8E10.3)
 1013 FORMAT(/2X*OTHER IMPACTS        WASTE PROCESSING     TRANSP    *,
+     *DISPOSAL   LT CARE*,2X,2F5.3/16X*      GENERAT  DISPOSAL*/2X,
+     *COST ($)*8X,5E10.2/2X*UNIT COST ($/M3)*5E10.2/2X*POP DOSE (MREM) *,
+     4F10.2/2X*OCC DOSE (MREM) *4F10.2/2X,16HLAND USE (M**2) ,4F10.2/2X,
+     *ENERGY USE (GAL)*4F10.2)
 1014 FORMAT(/2X*EXPOSE/ACC IMPACTS*)
 1015 FORMAT(12X,A10,8E10.3)
 1016 FORMAT(//2X*SINGLE CONTAINER ACCIDENT - ALL STREAMS*)
 1017 FORMAT(//2X*ACCIDENT BY FIRE - ALL STREAMS*)
 1018 FORMAT(14X,*STREAM*,5X,*BODY       BONE       LIVER    THYROID    *
+     *KIDNEY    LUNG    G-I TRACT    ICRP*)
 1020 FORMAT(12X,A10,8E10.3)
      STOP $ END
C
```

Listing for OPTIONS Computer Code (continued)

```
C
      SUBROUTINE COMBYN(NSTR,NNUC,NDX)
C
C     THIS SUBROUTINE READS THE DATA FILES, TAPE1 AND TAPE2, AND
C     PERFORMS SEVERAL BASIC CALCULATIONS TO INTEGRATE SOME OF
C     THE INFORMATION.  IT PERFORMS THE FOLLOWING:
C     1 : READ THE COMMON BLOCKS BAST, NUCS, AND DTIS
C     2 : USING THE VRF AND VIF GIVEN IN ISPC MATRIX MODIFIES
C         VOLUMES AND CONCENTRATIONS
C     3 : CALCULATES TRANSPORTED VOLUME AND STORES IT ON BAS(ISTR,28)
C     4 : CALCULATES THE WASTE PROCESSING IMPACTS
C     5 : MODIFIES H-3 AND C-14 CONC IF WASTE IS INCINERATED
C     6 : CALCULATES THE RET(23,5) MATRIX FROM GIVEN INFORMATION.
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8),FICRP(7)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)/DTIS/FSC(6),FSA(6),
+           PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),
+           DTPC(6),TPO(6,2),NRET(6)
      DIMENSION AZR(36),UPRS(7,3),USOL(3,3),USAV(3),
+               DEC(23,2),TPOP(2),NDX(36)
C
C
C     ADDITIONAL INFORMATION NECESSARY FOR THIS ROUTINE ARE GIVEN
C     IN THE ARRAYS AND DATA STATEMENTS.  THE ARRAYS ARE FOLLOWING:
C     AZR(36)    = SPECTRUM 1 VIF/VRF RATIOS
C     UPRS(7,3)  = VOLUME REDUCTION UNIT IMPACTS
C     USOL(3,3)  = SOLIDIFICATION UNIT IMPACTS
C     USAV(3)    = UNIT SAVINGS RESULTING FROM VOLUME REDUCTION
C     DEC(23,1)  = DECON FACTORS FOR PATHOLOGICAL INCINERATOR,
C                  AND DEC(23,2) IS THE DECON FACTORS FOR CALCINER.
C     TPOP(2)    = PERSON-YEAR/M3 ATMOSPHERIC DISPERSION FACTORS
C     FOR POPULATION EXPOSURE CALCULATION FOR URBAN AND RURAL AREAS.
C
      DATA AZR/1.,1.4,3*1.,1.4,15*1.,4*3.,2*1.92,3*1.,2.,1.3,4*1./
      DATA UPRS/335.,503.,1006.,690.,2060.,1938.,1039.,3*4.6,
+          56.3,116.,129.,72.,3*15.,4.42,8.,6.12,5.35/,
+     USOL/1282.,1873.,2445.,3*40.,3*24./,
+     USAV/210.,.4,4./,TPOP/1.56E-8,1.56E-10/,DEC/.9,.75,6*2.5E-3,
+        2*1.E-2,13*2.5E-3,.9,.25,6*2.5E-5,2*1.E-4,13*2.5E-5/
      READ(1,101)NSTR,NNUC,FICRP
      DO 70 I=1,NSTR
      READ(1,102)(BAS(I,J),J=1,27)
      READ(2,103)(ISPC(I,J),J=1,10)
   70 CONTINUE
      DO 80 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO 75 K=1,8
      READ(1,106)(DCF(I,J,K),J=1,7)
   75 CONTINUE
   80 CONTINUE
      DO 90 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
+     (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),(RGF(I,J),J=1,3),(POP(I,J),J=1,3),
+     NRET(I),DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   90 CONTINUE
```

```
  101 FORMAT(2I5,7F5.2)
  102 FORMAT(A10,2E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3/10X,6E10.3)
  103 FORMAT(10X,10I5)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4E10.3)
  106 FORMAT(10X,7E10.3)
      DO 50 ISTR=1,NSTR
      A1=ISPC(ISTR,2) $ A1=A1/ISPC(ISTR,3)
      A2=BAS(ISTR,3)/3.62 $ A3=A2/A1 $ BAS(ISTR,3)=A3
      DO 20 I=5,27
   20 BAS(ISTR,I)=BAS(ISTR,I)*A1
      BAS(ISTR,28)=BAS(ISTR,3) $ J=ISPC(ISTR,10)
C
C     THE FACTOR 3.62 IS THE NORMALIZATION VALUE
C     FOR ONE MILLION CUBIC METERS.
C     THE NEXT SECTION UNSCRAMBLES THE PROCESSING INDEX AND GETS
C     THE VOLUME REDUCTION METHOD - IP, SOLIDIFICATION - IS,
C     LOCATION - IL, AND ENVIRONMENT - IH.  IF IL=0 THEN THERE IS
C     NO PROCESSING AND THE SECTION IS SKIPPED, IF IL=2 THEN
C     THE DISPOSAL AND TRANSPORTATION VOLUMES ARE DIFFERENT
C
      BAS(ISTR,4)=BAS(ISTR,4)*A1
      IP=J/1000 $ IS=(J/100)-IP*10 $ IL=(J/10)-IP*100-IS*10
      IH=J-IP*1000-IS*100-IL*10 $ IF(NDX(ISTR).EQ.2)GO TO 31
      IF(IL.EQ.0) GO TO 50
      IF(IL.NE.2) GO TO 25
      BAS(ISTR,28)=A2 $ BAS(ISTR,4)=BAS(ISTR,4)/A1
   25 A5=0.5 $ IF(ISTR.GT.11)A5=0.1
C
C     NEXT DO LOOP CALCULATES WASTE PROCESSING IMPACTS
C
      DO 30 J=1,3
      A4=-A3*(AZR(ISTR)*A1-1.)*USAV(J)
      IF(IP.GT.0)A4=A4+A2*UPRS(IP,J)
      IF(IS.GT.0)A4=A4+A3*USOL(IS,J)
      IF(J.EQ.3)A4=A4*A5
   30 BAS(ISTR,28+J)=A4
C
C     NEXT SECTION FOR STREAMS PUT IN HIGH INTEGRITY CONTAINERS
C
   31 IF(NDX(ISTR).NE.2) GO TO 32
      A4=A2*450.
      BAS(ISTR,29)=A4
      IF(IL.EQ.0) GO TO 50
   32 CONTINUE
C
C     NEXT SECTION SKIPPED IF WASTE IS NOT INCINERATED
C     OTHERWISE, LOCATION DEPENDENT POP DOSES ARE CALCULATED
C
      IF(IP.LT.5)GO TO 50
      A5=0. $ J=2 $ IF(IP.EQ.5)J=1
      IF(IH.NE.1.AND.IH.NE.2)IH=1
      DO 40 INUC=1,NNUC
      A4=BAS(ISTR,3)*BAS(ISTR,INUC+4)*DEC(INUC,J)*TPOP(IH)
      DO 40 I=1,7
   40 A5=A5+A4*FICRP(I)*DCF(INUC,I,8)
      BAS(ISTR,32)=A5
```

Listing for OPTIONS Computer Code (continued)

```
C
C     ONLY ICRP WEIGHTED POPULATION IMPACTS ARE CALCULATED
C     ABOVE, TWO STATEMENTS BELOW MODIFY H-3 AND C-14
C     CONCENTRATIONS TO ACCOUNT FOR LOSS UP THE STACK.
C
      BAS(ISTR,5)=(1.-DEC(1,J))*BAS(ISTR,5)
      BAS(ISTR,6)=(1.-DEC(2,J))*BAS(ISTR,6)
   50 CONTINUE
      RETURN $ END
C
C
      SUBROUTINE RCLAIM(ISTR,NNUC,IMOD,IDX)
C
C     THIS ROUTINE CALCULATES THE INTRUDER IMPACTS FOR TWO PATHWAYS
C     - CONTRUCTION AND AGRICULTURE - AND DETERMINES THE STATUS OF
C     EACH WASTE STREAM ISPC(ISTR,11) AND DETERMINING TEST
C     CONDITION (IMOD).
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+          ,/DTIS/FSC(6),FSA(6)/IMPS/D7(8,7,2)
      DIMENSION EMP(5),DLC(7)
C
      DATA EMP/.5,.75,.5,.5,.75/,DLC/2*500.,1500.,3000.,3*1500./
      I5=ISPC(ISTR,5) $ I6=ISPC(ISTR,6) $ I7=ISPC(ISTR,7)
      I8=ISPC(ISTR,8) $ I9=ISPC(ISTR,9)
      IF(IDX.GT.1) I8=1
      A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
      CALL ZERO(D7,112) $ IF(I7.EQ.1.OR.IS.EQ.0) I6=I6-1
      FDES=EMP(IE)*(1.-.9*IG)
      A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
      A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
C
C     NEXT SECTION CALCULATES INTRUDER IMPACTS UNDER EIGHT
C     CONDITIONS (LOOP 35) AND SUBSEQUENTLY TESTS FOR STATUS ASSIGNMENT.
C     ULTIMATELY WASTE STREAM WILL BE CLASSIFIED AS EITHER NOT
C     ACCEPTABLE,REGULAR,LAYERED, OR HOT.
C
      DO 35 I3=1,8
      GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
      GO TO (11,12,13,14,15,16,17,18),I3
   11 A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   12 A4C=0.012 $ A4A=0. $ A8C=0.012*A7 $ A8A=0. $ GO TO 20
   13 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   14 A4C=0.1 $ A4A=0. $ A8C=A7/1200. $ A8A=0. $ GO TO 20
   15 A4C=0.0012 $ A4A=0. $ A8C=0.0012*A7/1200. $ A8A=0. $ GO TO 20
   16 GDEL=IPO+500. $ A4C=1. $ A4A=1. $ A8C=A7 $ A8A=A7 $ GO TO 20
   17 A8C=0.1*A7/1.44E6 $ IF(IG.EQ.0)A8C=A8C*0.1
      A4C=0.01 $ A4A=0. $ A8A=0. $ GO TO 20
   18 GDEL=IPO+1000. $ A8C=A7 $ IF(IG.EQ.0)A8C=0.1*A7
      A4C=1. $ A4A=1. $ A8A=A8C
```

Listing for OPTIONS Computer Code (continued)

```
   20 DO 30 INUC=1,NNUC
      A1=A9*FDES*EXM(AL(INUC)*GDEL)*BAS(ISTR,INUC+4)
      DO 25 I=1,7
      A2=DCF(INUC,I,5)
      B1=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
      B2=A1*A8C*A2*0.057
      B3=0.25*A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)
      B4=0.5*0.25*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
C     B1=A1*A4C*FSC(IR)*DCF(INUC,I,2)
C     B3=0.25*A1*A4A*FSA(IR)*DCF(INUC,I,3)
C     B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)
      B5=0.25*A1*A8A*A2*0.27
      DZ(I3,I,1)=DZ(I3,I,1)+B1+B2
   25 DZ(I3,I,2)=DZ(I3,I,2)+B3+B4+B5
   30 CONTINUE
   35 CONTINUE
C
C     ALL CONDITIONS TESTED - NOW DETERMINE WASTE STATUS
C
      I3=1 $ IF(IS.EQ.1.AND.IR.EQ.1) I3=2
      IF(ID.EQ.2) I3=2
      I30=I3
      IF(IDX.EQ.0) GO TO 70
   40 DO 50 IORG=1,7
      DO 50 IPTH=1,2
      IF(DZ(I3,IORG,IPTH).GT.DLC(IORG)) GO TO 60
   50 CONTINUE
      GO TO (51,52,51,53,53,54,55,56),I3
   51 ISPC(ISTR,11)=1
      IMOD=1 $ IF(I30.EQ.2) IMOD=2
      RETURN
   52 I3=3 $ GO TO 40
   53 I3=6 $ GO TO 40
   54 ISPC(ISTR,11)=2
      IMOD=4 $ IF(I30.EQ.2) IMOD=5
      RETURN
   55 I3=8 $ GO TO 40
   56 ISPC(ISTR,11)=3 $ IMOD=7
      RETURN
   60 GO TO (61,62,63,63,63,63,70,70),I3
   61 IF(IL.EQ.0)GO TO 63
      I3=4 $ GO TO 40
   62 IF(IL.EQ.0)GO TO 63
      I3=5 $ GO TO 40
   63 IF(IH.EQ.0)GO TO 70
      I3=7 $ GO TO 40
   70 ISPC(ISTR,11)=0
      RETURN $ END
C
C
```

Listing for OPTIONS Computer Code (continued)

```
      SUBROUTINE ACCEXP(NSTR,NNUC,NDX)
C
C     THIS ROUTINE CALCULATES THE EXPOSURE AND ACCIDENT IMPACTS
C     FOR 7 PATHWAYS (4 EXPOSURE AND 3 ACCIDENT) AND 7 ORGANS.
C
      COMMON/BAST/BAS(36,32),ISPC(36,11),DCF(23,7,8)
+            /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+            /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+            /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
+            TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+            /IMPS/DZDM(168),DZA(7,7),DZS(36,7,2)
      DIMENSION EMP(5),EFF(2),SEFF(2),NDX(36)
      DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,SEFF/0.9,0.35/
      VTOP=0. $ VTOT=0. $ VHOT=0. $ GREC=IPO+IIC
C
C     EROSION TIME SCALE DEPENDENT ON COVER USED AT DISPOSAL SITE
C
      GERO=IPO+2000.
      IF(IC.EQ.2) GERO=IPO+3000.
      IF(IC.EQ.3) GERO=IPO+10000.
      IF(ID.EQ.2) GERO=IPO+10000.
      DO 10 ISTR=1,NSTR
      I1=ISPC(ISTR,11)
      IF(I1.EQ.1)VTOP=VTOP+BAS(ISTR,3)
      IF(I1.EQ.1.OR.I1.EQ.2)VTOT=VTOT+BAS(ISTR,3)
      IF(I1.EQ.3)VHOT=VHOT+BAS(ISTR,3)
   10 CONTINUE
C
C     VTOP IS JUST REGULAR WASTE
C     VTOT IS REGULAR + LAYERED WASTE
C
C
C     NEXT SECTION ESTABLISHES AREAL FACTORS FOR 4 EXPOSURE PATHWAYS
C
      FRA=5.72E-5*POP(IR,1)*1.8E+3 $ VUR=EMP(IE)*EFF(ID)*SEFF(ID)
      FEA=8.09E-6*POP(IR,2)*VTOT/VUR
      FRW=1.15E-4*POP(IR,3)*1.8E+3
      FEW=1.15E-4*POP(IR,3)*VTOT/VUR
C
C     MAIN LOOP FOR EXPOSURE IMPACTS
C
      DO 40 ISTR=1,NSTR
      A1=0.25 $ I11=ISPC(ISTR,11) $ IF(I11.EQ.0)GO TO 40
      I5=ISPC(ISTR,5) $ A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      I9=ISPC(ISTR,9) $ A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
      I8=ISPC(ISTR,8) $ IF(NDX(ISTR).GT.1) I8=1
      IF(I8.EQ.1.AND.IS.EQ.1)A1=0.012/9.
      IF(I11.EQ.2.OR.ID.EQ.2)A1=A1*0.01
      IF(I11.EQ.3)A1=1.2E-5/9.
      A2=EMP(IE)*SEFF(ID)*BAS(ISTR,3)/VTOP
      A3=A2*VTOP/(VTOT+VHOT) $ IF(I11.GT.1)A2=0.
      IF(ID.EQ.2.AND.I11.NE.2) A2=A3
```

Listing for OPTIONS Computer Code (continued)

```
      DO 30 INUC=1,NNUC
      A6=EXM(GREC*AL(INUC)) $ A7=EXM(GFRO*AL(INUC))
      A8=BAS(ISTR,INUC+4)
      B1=FRA*A1*A3*A6*A8*A5    $ B2=FEA*A2*A7*A8
      B3=FRW*A1*A3*A6*A8*A9    $ B4=FEW*A2*A7*A8
      DO 20 IORG=1,7
      DZA(IORG,1)=DZA(IORG,1)+B1*DCF(INUC,IORG,8)
      DZA(IORG,2)=DZA(IORG,2)+B2*DCF(INUC,IORG,8)
      DZA(IORG,3)=DZA(IORG,3)+B3*DCF(INUC,IORG,7)
      DZA(IORG,4)=DZA(IORG,4)+B4*DCF(INUC,IORG,7)
   20 CONTINUE
   30 CONTINUE
   40 CONTINUE
C
C     END EXPOSURE LOOP
C
      VSC=0. $ VFR=0.
C
C     MAIN LOOP OF ACCIDENT IMPACTS
C
      DO 80 ISTR=1,NSTR
      I3=ISPC(ISTR,11) $ IF(I3.EQ.0.OR.I3.EQ.3)GO TO 80
      I4=ISPC(ISTR,4) $ I6=ISPC(ISTR,6) $ I9=ISPC(ISTR,9)
      A5=BAS(ISTR,3) $ IF(I9.GT.1) GO TO 80
      FAF=TPO(IR,1) $ FAS=TPO(IR,2)
      IF(I6.GT.1) FAS=FAS*(10.**(1-I6))
      IF(I4.LT.3) FAF=FAF*(20.**(I4-3))
      IF(IS.EQ.1.AND.I4.NE.3) FAF=0.
C
C     DISTINGUISH BETWEEN SINGLE CONTAINER AND FIRE ACCIDENTS
C
      VFR=VFR+A5
      VSC=VSC+A5
      DO 70 INUC=1,NNUC
      A1S=FAS*BAS(ISTR,INUC+4)*A5
      A1F=FAF*BAS(ISTR,INUC+4)*A5
      DO 70 IORG=1,7
      DZS(ISTR,IORG,1)=DZS(ISTR,IORG,1)+A1S*DCF(INUC,IORG,1)/A5
      DZS(ISTR,IORG,2)=DZS(ISTR,IORG,2)+A1F*DCF(INUC,IORG,1)/A5
      DZA(IORG,5)=DZA(IORG,5)+A1S*DCF(INUC,IORG,1)
   70 DZA(IORG,6)=DZA(IORG,6)+A1F*DCF(INUC,IORG,1)
   80 CONTINUE
C
C     END OF ACCIDENT LOOP
C
C
C     LAST PATHWAY IS AVERAGED ACCIDENT
C
      DO 90 IORG=1,7
      DZA(IORG,7)=(DZA(IORG,5)+DZA(IORG,6))/(VSC+VFR)
      IF(VSC.GT.0.) DZA(IORG,5)=DZA(IORG,5)/VSC
      IF(VFR.GT.0.) DZA(IORG,6)=DZA(IORG,6)/VFR
   90 CONTINUE
      RETURN $ END
C
```

Listing for OPTIONS Computer Code (continued)

```
05440C
05450       SUBROUTINE TRANSP(TIMP,NSTR)
05460C
05470C      THIS ROUTINE DETERMINES THE TRANSPORTATION SCHEME FOR ALL
05480C      WASTE STREAMS BASED PRIMARILY ON THE PACKAGING INDEX OF
05490C      THE SPECTRUM FILES AND THE ACTIVITY CONCENTRATIONS OF THE
05500C      INDIVIDUAL STREAMS. ULTIMATE RESULT IS THE TRANSPORTATION
05510C      IMPACTS (TIMP).
05520C
05530       COMMON/BAST/BAS(36,32),ISPC(36,11)/DTNX/IR,ID,IC,IX,IF
05540       DIMENSION PCAR(6,3),PPAK(8,6),KON(18),TYM(2,18),KWT(18),
05550+      RDZ(2,3),PKV(5),TDZ(2,2),TCST(2,3),TIMP(6),TVOL(5,3),
05560+      DUM1(3),DUM2(3),DUM3(3,3),DIST(6),STPS(6),CASK(6)
05570C
05580C      THE ABOVE ARRAYS AND MATRICES ARE EXPLAINED BELOW:
05590C            PCAR(6,3)    : CONTAINS 6 DISTRIBUTIONS OF 3 CARE TYPES.
05600C            PPAK(8,6)    : CONTAINS 8 DISTRIBUTIONS OF 5 PACKING
05610C                           CONTAINERS + A POSITIONING INDEX.
05620C            KON(18)      : MULTIPLE INDEX WHICH DESCRIBES PACKING
05630C                           CAPABILITIES FOR 3 CARE TYPES AND 5
05640C                           CONTAINERS.
05650C            TYM(2,18)    : TIME IN MINUTES FOR UNLOADING OF WASTE
05660C                           (CONTACT TIME) - CORRESPONDING TO THE
05670C                           18 KON INDICES ABOVE.
05680C            TCST(2,3)    : TRANSPORTATION COST ($) PER MILE.
05690C            RDZ(2,3)     : RADIOLOGICAL COST (DOSE) PER HOUR OF
05700C                           CONTACT TIME WITH WASTE.
05710C            TDZ(2,2)     : TWO PART TRANSPORTATION DOSE: PER MILE,
05720C                           AND LUMP SUM PARAMETERS.
05730C            PKV(5)       : VOLUME CAPACITY FOR EACH OF 5 CONTAINERS.
05740C            KWT(18)      : INDEX TO RELATE TRANSPORT VEHICLE OVER-
05750C                           WEIGHT STATUS TO EACH OF KON INDICES.
05760C            DIST(6)      : TRAVEL DISTANCE TO DISPOSAL SITE IN
05770C                           VARIOUS REGIONS.
05780C            STPS(6)      : STATE INSPECTION STOPS TO BE EXPECTED
05790C                           WITHIN A PARTICULAR REGION.
05800C            CASK(6)      : NUMBER OF DAYS A CASK WOULD BE REQUIRED
05810C                           IN A PARTICULAR REGION.
05820C            OTHER ARRAYS AND MATRICES DESCRIBED FURTHER ON IN PROGRAM.
05830C
05840       DATA PCAR/1.,.8,.4,.2,.1,0.,0.,.2,.5,.6,.5,.2,0.,0.,.1,.2,.4,.8/
05850       DATA PPAK/0.,.23,5*0.,.1,.0.,.08,.025,5*0.,.69,.69,.975,.2,1.,
05860+      3*0.,.15,0.,0.,.8,0.,.5,2*0.,.16,4*0.,.5,1.,0.,.3,.1,.2,.4*3.,.1./
05870       DATA KON/1103024,1104076,1236100,1370100,1411100,-1501100,
05880+            2103100,2236096,-2206004,2370048,-2314051,-2306001,
05890+            -2402100,-2501100,-3306051,-3301049,-3402100,-3501100/
05900       DATA TYM/200.,240.,74.,120.,16.,24.,6.,24.,136.,165.,1200.,1440.,
05910+            300.,360.,26.,39.,250.,300.,10.,24.,86.,175.,200.,312.,
05920+            600.,720.,1200.,1440.,200.,312.,600.,720.,600.,720.,
05930+            1500.,1800./,TCST/1.69,1.25,1.47,1.14,1.17,1.08/
05940       DATA RDZ/500.,750.,1200.,1800.,2200.,2200./,TDZ/1.8E-2,
05950+            2.0E-2,2.,2./,PKV/3.625,.453,.208,1.416,4.814/
05960       DATA KWT/16*0,2*1/,DIST/300.,400.,600.,1000.,2*400./,
05970+            STPS/2*1.,2.,3.,2*1./,CASK/2.,3.,5.,8.,2*3./
05980       CALL ZERO(TIMP,6) $ CALL ZERO(TVOL,15)
05990C
```

```
C     THIS SECTION -DO LOOP 160- DISTRIBUTES THE WASTE INTO THREE
C     CARE TYPES AND AMONG FIVE PACKING CONTAINERS. (3 CONTAINERS
C     ARE CONSIDERED IN EACH LOOP - IF APPLICABLE TO THAT STREAM.)
C
      DO 160 IPAK=1,8
      NX=0 $ CALL ZERO(DUM1,3)
C
C     DO LOOP 70 DISTRIBUTES WASTE AMONG CARE TYPES
C
      DO 70 ISTR=1,NSTR
      IF(ISPC(ISTR,11).EQ.0)GO TO 70
      I2=IABS(ISPC(ISTR,1))
      I1=I2/10 $ IF(I1.NE.IPAK)GO TO 70
      I3=I2-I1*10 $ A1=BAS(ISTR,28)
C
C     I1 = PACKAGING INDEX      I3 = CARE TYPE INDEX
C
C     FOLLOWING SECTION DETERMINES I4 - INDEX FOR CARE TYPE
C     DISTRIBUTION - BASED ON UNDECAYED TOTAL ACTIVITY OF STREAM.
C
      A2=BAS(ISTR,4)*100. $ IF(I3.EQ.2) A2=BAS(ISTR,4)*10.
      NX=1 $ IF(I3.GT.2) GO TO 40
      I5=ALOG10(A2)
      IF(I3.EQ.2) GO TO 30
      IF(A2.LT.1.) I4=1
      IF(A2.GE.1.) I4=I5+2
      IF(I4.GT.6) I4=6
      GO TO 50
   30 IF(A2.LT.1.) I4=1
      IF(A2.GE.1.) I4=I5+2
      IF(I4.GT.4) I4=4
      GO TO 50
   40 I4=I3-2
   50 DO 60 I=1,3
   60 DUM1(I)=DUM1(I)+PCAR(I4,I)*A1
   70 CONTINUE
C
C     DUM1 CONTAINES WASTE VOLUME IN EACH OF 3 CARE TYPES
C
      IF(NX.EQ.0) GO TO 160
      A1=DUM1(1)+DUM1(2)+DUM1(3)
      I2=PPAK(IPAK,6)+0.1
C
C     DO LOOP 80 DISTRIBUTES WASTE AMONG CONTAINERS
C
      DO 80 I=1,3
      II=I-1
   80 DUM2(I)=PPAK(IPAK,I2+II)*A1
C
C     DUM2 CONTAINS WASTE VOLUME IN EACH OF 3 CONTAINERS CONSIDERED
C     IN THIS LOOP OF 160
C
      CALL ZERO(DUM3,9)
C
```

Listing for OPTIONS Computer Code (continued)

```
C     DO LOOP 130 DETERMINES PACKAGING STRATEGY FOR 3 CARE TYPES AND
C     3 CONTAINERS CONSIDERED FOR THIS LOOP OF IPAK. RESULTS ARE
C     PLACED IN DUM3.
C
      DO 130 J=1,3
      DO 120 I=1,3
      IF(DUM1(J).LE.0.0) GO TO 130
      IF(DUM2(I).LE.0.0) GO TO 120
      IF(DUM1(J)-DUM2(I))90,100,110
   90 DUM3(I,J)=DUM1(J)
      DUM2(I)=DUM2(I)-DUM1(J)
      DUM1(J)=-1.0 $ GO TO 130
  100 DUM3(I,J)=DUM1(J)
      DUM2(I)=-1.0 $ DUM1(J)=-1.0 $ GO TO 130
  110 DUM3(I,J)=DUM2(I)
      DUM1(J)=DUM1(J)-DUM2(I)
      DUM2(I)=-1.0
  120 CONTINUE
  130 CONTINUE
      DO 150 I=1,3
      II=I-1
      DO 150 J=1,3
  150 TVOL(I2+II,J)=TVOL(I2+II,J)+DUM3(I,J)
  160 CONTINUE
C
C     TVOL CONTAINS TOTAL WASTE VOLUME DISTRIBUTED FOR 3 CARE TYPES
C     AND 5 CONTAINERS FOR ALL WASTE STREAMS.
C
C
C     THIS SECTION -DO LOOP 240- CALCULATES THE TRANSPORTATION
C     IMPACTS RESULTING FROM TVOL DISTRIBUTION. (18 LOOPS REQUIRED
C     FOR CHARACTERIZING THE 3 CARE TYPES AND 5 CONTAINERS USED
C     IN THIS PROGRAM)
C     RESULTS ARE PLACED IN TIMP ARRAY, WHERE:
C           TIMP(1) = DOLLARS
C           TIMP(2) = ENERGY USE
C           TIMP(3) = TRANSPORTATION OCCUPATIONAL DOSE
C           TIMP(4) = TRANSPORTATION POPULATION DOSE
C           TIMP(5) = DISPOSAL SITE OCCUPATIONAL DOSE (UNLOADING)
C           TIMP(6) = TRANSPORTATION OCCUPATIONAL DOSE (LOADING)
C
C
      DO 240 IKON=1,18
      II=KON(IKON) $ NX=1 $ FRC=1.0
C
C     IF KON INDEX IS NEGATIVE THEN RETURN TRIP IS NECESSARY.
C
      IF(II.GT.0) GO TO 210
      II=-II $ NX=2
  210 I3=II/100000 $ I2=I3/10 $ I1=I3-I2*10
      I5=II-I3*100000 $ I3=I5/1000 $ I4=I5-I3*1000
C
C     IN ABOVE SECTION KON BROKEN UP INTO:
C     I1 = PACKAGE TYPE        I3 = NO. OF PACKAGES THIS SHIPMENT
C     I2 = CARE TYPE           I4 = PCT. OF WASTE SENT THIS SHIPMENT
C
```

Listing for OPTIONS Computer Code (continued)

```
      IF((I2.EQ.1).OR.(I2.EQ.2.AND.NX.EQ.2)) FRC=0.1
      FRS=I4/100 $ A1=TVOL(I1,I2)*FRS
      IF(A1.LT.1.E-06) GO TO 240
      KSHP=A1/(I3*PKV(I1))+1.0
      A2=KSHP*DIST(IR) $ A3=A2*NX
      TIMP(2)=TIMP(2)+A3/6.
C
C     IN ABOVE EQUATION 6 REPRESENTS MILES PER GALLON FUEL CONSUMPTION.
C
      TIMP(4)=TIMP(4)+(A2*TDZ(1,1)+KSHP*TDZ(1,2)*STPS(IR))*FRC
      TIMP(3)=TIMP(3)+(A2*TDZ(2,1)+KSHP*TDZ(2,2)*STPS(IR))*FRC
      NC=3 $ IF(DIST(IR).GT.400..AND.DIST(IR).LT.1000.) NC=2
      IF(DIST(IR).LE.400.) NC=1
      TIMP(1)=TIMP(1)+A3*TCST(NX,NC)*1.15
C
C     IN NEXT SECTION CASK RENTAL FEE AND OVERWEIGHT FEE ADDED -
C     IF APPLICABLE.
C
      IF(NX.EQ.1) GO TO 220
      TIMP(1)=TIMP(1)+KSHP*CASK(IR)*250.
      IF(KWT(IKON).GT.0)TIMP(1)=TIMP(1)+A2*0.76+60.*STPS(IR)
  220 KPAK=A1/PKV(I1)+1.0
      NX=2 $ IF(IE.EQ.1.OR.IE.EQ.4) NX=1
      FRC=1.0 $ IF(IE.EQ.3) FRC=2.0
      A2=KPAK*TYM(NX,IKON)/60.
      TIMP(5)=TIMP(5)+A2*FRC*RDZ(NX,I2)*1.E-3
      TIMP(6)=TIMP(6)+A2*RDZ(2,I2)*1.E-3
  240 CONTINUE
      RETURN $ END
C
C
      SUBROUTINE ECON(NSTR,RI,RJ,COST,NDX)
C
C     THIS ROUTINE CALCULATES THE DISPOSAL IMPACTS BASED LARGELY
C     ON THE INPUTED VALUES FOR THE DISPOSAL TECHNOLOGY INDICES.
C     THE RESULTS OF THIS ROUTINE ARE PLACED IN ARRAY COST, WHERE:
C           COST(1) = PRE-OP AND OPERATIONAL DOLLARS
C           COST(2) = OCCUPATIONAL DOSE
C           COST(3) = ENERGY USE
C           COST(4) = LAND USE
C           COST(5) = POST-OP DOLLARS
C
      COMMON/BAST/BAS(36,32),ISPC(36,11)
      COMMON/DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
      COMMON/VOL/VREG,VLAY,VHOT
      DIMENSION EMP(5),EFF(2),AMULT(2),CONT(6),COST(5),SEFF(2)
      DIMENSION NDX(36)
C
C     THE SIGNIFICANT ARRAYS ABOVE ARE:
C     AMULT(2)    = CAPITAL AND OPERATIONS COST ($) MULTIPLIERS.
C     CONT(3)     = CONTINGENCY COST FOR SOIL PERMEABILITY CONDITIONS.
C     COST(5)     = CONTAINS RESULTANT IMPACTS - IN TERMS OF $,
C                   OCCUPATIONAL DOSE, ENERGY USE, LAND USE, AND
C                   POST OPERATIONAL $.
C
C
```

Listing for OPTIONS Computer Code (continued)

```
C     RI AND RJ PARAMETERS ARE INTEREST AND INFLATION RATES, RESPECTIVELY.
C
      DATA CONT/1007.,367.,367.,0.,168.,1007./,ITO,F/20.,.015/
      DATA EMP/.5,.75,.5,.5,.75/,EFF/6.4,7.0/,AMULT/10.38,1.56/,
     +     SEFF/.9,.35/
      CALL ZERO(COST,5)
      VSTAB=0. $ VUNS=0. $ DECON=0.
      DO 5 ISTR=1,NSTR
      I11=ISPC(ISTR,11)  $ I2=ISPC(ISTR,8)
      IF(NDX(ISTR).GT.1) I2=1
      IF(I11.EQ.0.OR.I11.EQ.3) GO TO 5
      IF(IE.EQ.3.AND.I2.EQ.0) DECON=DECON+BAS(ISTR,3)
      IF(I2.EQ.0) VSTAB=VSTAB+BAS(ISTR,3)
      IF(I2.EQ.1) VUNS=VUNS+BAS(ISTR,3)
    5 CONTINUE
      IF(IE.EQ.3) IS=1
C
C     VSTAB %_ VUNS CONTAIN STABLE AND UNSTABLE WASTE VOLUMES,RESPECTIVELY
C
      DREG=(VREG+VLAY)*1.E-06 $ DHOT=VHOT*1.E-06
      DLAY=VLAY*1.E-06          $ DECON=DECON*1.E-06
      DVOL=DREG/EMP(IE)         $ DAREA=DVOL/(EFF(ID)*SEFF(ID))
      GV=(1.-EMP(IE))*DVOL $ VTOT=VREG+VLAY+VHOT
      SV=DREG*((1.1567/EMP (IE))-1.)
C
C     VOLUME AND AREA VALUES ARE EXPRESSED IN UNITS OF MILLION M3 OR M2
C     FOR USE IN COST EVALUATIONS. GV IS GROUT VOLUME. SV IS SAND VOLUME.
C
      COST(4)= (DAREA           +(DHOT/1.84))*1.E6
      S1=(VSTAB/VREG)*DAREA $ S2=(VUNS/VREG)*DAREA
C
C     IN FOLLOWING SECTION C1,C2, AND C3 WILL ACCUMULATE THE DOLLAR,
C     DOSE, AND ENERGY COSTS THROUGH THE VARIOUS PHASES OF THE SITE LIFE.
C
C
C     PRE-OPERATIONAL (CAPITAL) COSTS
C
C     ******** REFERENCE BASE CASE ********
      C1=7452. $ COST(3)=212.
C     ******** ADDITIVE ALTERNATIVES ******
      IF(ID.EQ.2) C1=C1+593.5
      IF(IE.EQ.2 .OR.IE.EQ.5) C1=C1+225.5
      IF(IS.EQ.1) C1=C1+0.99
      IF(IL.EQ.1) C1=C1+132.
      IF(IE.EQ.3) C1=C1+924.3
      IF(IH.EQ.1) C1=C1+259.4
      IF(IG.EQ.1) C1=C1+55.
      IF(IC.EQ.3) C1=C1+280.5
      IF(IX.EQ.3) C1=C1+9.9
      CAP=C1*AMULT(1)
C
C
```

Listing for OPTIONS Computer Code (continued)

```
C     OPERATIONAL COSTS
C
C     ******** REFERENCE BASE CASE ********
      C1=2341.*DVOL $ C2=300.*DVOL $ C3=200.*DVOL
      C1=C1+1420.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+100.*DAREA
      C1=C1+63696. $ C2=C2+1000. $ C3=C3+200.
C
C     ******** ADDITIVE ALTERNATIVES ******
      IF(ID.NE.2) GO TO 20
      C1=C1+74438.*DVOL $ C2=C2+700.*DVOL $ C3=C3+300.*DVOL
   20 IF(IE.LT.5.AND.NE.2) GO TO 25
      C1=C1+12758.*DREG $ C2=C2+100.*DREG $ C3=C3+100.*DREG
   25 IF(IS.NE.1) GO TO 30
      C1=C1+3888.*DREG $ C2=C2+100.*DREG $ C3=C3+30.*DREG
   30 IF(IL.NE.1) GO TO 35
      C1=C1+15400.*DLAY $ C2=C2+100.*DLAY $ C3=C3+30.*DLAY
   35 IF(IE.NE.3) GO TO 40
      C1=C1+48975.*DECON $ C2=C2+400.*DECON $ C3=C3+100.*DECON
   40 IF(IH.NE.1) GO TO 45
      C1=C1+176979.*DHOT $ C2=C2+(-200.)*DHOT $ C3=C3+450.*DHOT
   45 IF(IG.NE.1) GO TO 46
      C1=C1+72405.*GV $ C2=C2+2550.*GV $ C3=C3+800.*GV
   46 IF(IE.LT.4) GO TO 50
      C1=C1+3270.*SV $ C3=C3+150.*DAREA
   50 IF(IC.NE.2) GO TO 55
      C1=C1+15524.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+150.*DAREA
   55 IF(IC.NE.3) GO TO 60
      C1=C1+103854.*DAREA $ C2=C2+2400.*DAREA $ C3=C3+300.*DAREA
   60 IF(IX.EQ.1) GO TO 75
      S3=S2
      IF(IS.EQ.0) S3=S1+S2
      IF(ID.EQ.2) S3=0.
      IXX=IX-1 $ GO TO (65,70),IXX
   65 C1=C1+3465.*S3 $ C2=C2+4800.*S3 $ C3=C3+300.*S3
      GO TO 75
   70 C1=C1+33345.*S3 $ C2=C2+4800.*S3 $ C3=C3+600.*S3
   75 OPS=C1*AMULT(2)
      COST(2)=COST(2)+C2 $ COST(3)=COST(3)+C3
C
C
C     POST-OPERATIONAL COSTS
C
C     ICL IS BROKEN INTO TWO PARTS TO INDICATE THE LEVEL OF
C     CLOSURE AND INSTITUTIONAL CARE, RESPECTIVELY.
C
C     ******** CLOSURE PERIOD ********
      ICL1=ICL/10 $ ICL2=ICL-ICL1*10
      C1=1010. $ C2=500. $ C3=15.
      IF(ICL1.NE.2) GO TO 76
      C1=3025. $ C2=1000. $ C3=60.
C
```

```
C     ********* INSTITUTIONAL PERIOD ****
C
C     DOLLAR COST SECTION
C
   76 CA=150. $ CB=63. $ CC=51.
      IF(ICL2.NE.2) GO TO 77
      CA=303. $ CB=150. $ CC=63.
   77 IF(ICL2.NE.3) GO TO 78
      CA=440.+CONT(IR) $ CB=303. $ CC=150.
   78 S1=0. $ S2=0. $ S3=0.
      DO 80 N=1,10
      E=N
      D1=(1.+RJ)**E $ D2=(1.+RI)**E
   80 S1=S1+D1/D2
      DO 85 N=11,25
      E=N
      D1=(1.+RJ)**E $ D2=(1.+RI)**E
   85 S2=S2+D1/D2
      DO 90 N=26,IIC
      E=N
      D1=(1.+RJ)**E $ D2=(1.+RI)**E
   90 S3=S3+D1/D2
      PV80=CA*S1+CB*S2+CC*S3
      M=IPO+ITO
      EM=M $ EITO=ITO $ EIPO=IPO
      D1=(1.+RJ)**EITO $ D2=(1.+RJ)**EM
      D3=(1.+RI)**EITO $ D4=(1.+RI)**EIPO
      U3=(EITO*PV80*D2*RI)/((D3-1.)*D4)
      U3=(EITO*C1*D1*F) + U3
      COST(1)=CAP+OPS $ COST(5)=U3
C
C      ENERGY USE SECTION
C
      IICC=(IIC-26)+1
      GO TO (100,110,120),ICL2
  100 C3=C3+10*5.+15*3.+IICC*1.
      GO TO 125
  110 C3=C3+10*10.+15*5.+IICC*3.
      GO TO 125
  120 C3=C3+10*12.+15*10.+IICC*5.
  125 CONTINUE
      COST(1)=COST(1)*1000.
      COST(2)=COST(2)+C2 $ COST(5)=COST(5)*1000.
      COST(3)=COST(3)+C3 $ COST(3)=COST(3)*1000.
      RETURN $ END
C
C     UTILITY SUBROUTINES
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
C
```

Listing for OPTIONS Computer Code (continued)

```
      FUNCTION FXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      FXM=A2
      RETURN $ END
      SUBROUTINE PRT(V,IQ,N,ID,NDX)
      COMMON/BAST/BAS(36,32),ISPC(36,11)
      DIMENSION IQ(36),LAB(4),NDX(36)
      DATA LAB/10HCH-STAR   ,10HCH-UNSTAR ,10HNCH-STAR  ,10HNCH-UNSTAR/
      IF(N.EQ.0)RETURN
      GO TO (10,10,50,70),ID
   10 IF(ID.EQ.1)WRITE(4,410)V
      IF(ID.EQ.2)WRITE(4,420)V
      DO 25 K=1,4
      IT=0 $ VTOT=0.
      DO 20 I=1,N
      ISTR=IQ(I)
      I8=ISPC(ISTR,8) $ I7=ISPC(ISTR,7)
      IF(NDX(ISTR).GT.1) I8=1
      IF(K.NE.1.AND.I7.EQ.1.AND.I8.EQ.1) GO TO 20
      IF(K.NE.2.AND.I7.EQ.1.AND.I8.EQ.0) GO TO 20
      IF(K.NE.3.AND.I7.EQ.0.AND.I8.EQ.1) GO TO 20
      IF(K.NE.4.AND.I7.EQ.0.AND.I8.EQ.0) GO TO 20
      IF(IT.EQ.0)WRITE(4,430)LAB(K),BAS(ISTR,1),BAS(ISTR,3)
      IF(IT.EQ.1)WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
      IT=1 $ VTOT=VTOT+BAS(ISTR,3)
   20 CONTINUE
      IF(IT.EQ.1) WRITE(4,470)VTOT
   25 CONTINUE
      RETURN
   50 WRITE(4,450)V
      DO 55 I=1,N
      ISTR=IQ(I)
   55 WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
      RETURN
   70 WRITE(4,460)V
      DO 75 I=1,N
      ISTR=IQ(I)
   75 WRITE(4,440)BAS(ISTR,1),BAS(ISTR,3)
  410 FORMAT(/2X*REGULAR WASTE :*,21X,E10.3,5H M**3)
  420 FORMAT(/2X*LAYERED WASTE :*,21X,E10.3,5H M**3)
  430 FORMAT(7X,A10,A10,E10.3)
  440 FORMAT(17X,A10,E10.3)
  450 FORMAT(/2X*HOT WASTE     :*,21X,E10.3,5H M**3)
  460 FORMAT(/2X*NOT ACCEPTABLE:*,21X,E10.3,5H M**3)
  470 FORMAT(18X*TOTAL VOLUME  :*5X,E10.3,5H M**3)
      RETURN $ END
```

Listing for INVERSI Computer Code

```
      PROGRAM INVERSI(INPUT,OUTPUT,TAPE1,TAPE2)
C
C     THIS IS THE INVERSE INTRUDER AND ACCIDENT CODE.  IT FINDS
C     THE INDIVIDUAL NUCLIDE CONCENTRATIONS NECESSARY TO REACH
C     DOSES ASSIGNED BY THE DLC (DOSE LIMITING CRITERIA).
C
      COMMON/BAST/DCF(23,7,8),FICRP(7)/DTNX/IRDC(12)
+           /NUCS/NUC(23),AL(23),EMF(23),RET(23,5)
+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
+                      RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+           /IMPS/DMY(23,8,14)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DTNX BLOCK CONTAINS THE DISPOSAL TECHNOLOGY INDICES.
C     DMY(23,8,14) WILL CONTAIN THE CONCENTRATIONS FOR ALL NUCLIDES,
C     7 ORGANS, AND SEVERAL PATHWAYS.
C
      DIMENSION DES(20),ORGAN(8),ISPC(11)
      DATA ORGAN/10H   BODY   ,10H   BONE   ,10H   LIVER  ,10H  THYROID ,
+                  10H  KIDNEY  ,10H   LUNG   ,10H  GI-LLI  ,10H  MINIMUM /
      DATA DES/10H UNS1-CON ,10H UNS1-AGR ,10H STA1-CON ,10H STA1-AGR ,
+              10H UNSL-CON ,10H UNSL-AGR ,10H STAL-CON ,10H STAL-AGR ,
+              10H GEN5-CON ,10H GEN5-AGR ,10H HWF1-CON ,10H HWF1-AGR ,
+              10H HWF2-CON ,10H HWF2-AGR ,10H INT-AIR  ,10H FRO-AIR  ,
+              10H INT-WAT  ,10H FRO-WAT  ,10H ACC-CONT ,10H ACC-FIRE /
C
C     THE ABOVE ARRAYS ARE:
C         DES(20)    : DESCRIPTION OF PATHWAYS USED IN BOTH INTRUDER
C                      AND ACCIDENT SCENARIOS.
C         ORGAN(8)   : DESCRIPTION OF 7 ORGANS + A MINIMUM COLUMN.
C         ISPC(11)   : SPECTRUM INDICES READ IN THRU INPUT.
C
      DATA AL240/1.05E-4/
C
C     NEXT SECTION READS IN - THRU TAPE1 - THE NUCLIDE AND REGIONAL
C     DATA NECESSARY FOR THIS PROGRAM.
C
      READ(1,101)NSTR,NNUC,FICRP
      DO 20 I=1,NNUC
      READ(1,104)NUC(I),AL(I),EMF(I),RET(I,1),RET(I,4)
      DO 10 K=1,8
      READ(1,106)(DCF(I,J,K),J=1,7)
   10 CONTINUE
   20 CONTINUE
      DO 30 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
+                 (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
+                 (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
+                 DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   30 CONTINUE
  101 FORMAT(2I5,7E5.2)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4E10.3)
  106 FORMAT(10X,7E10.3)
C
```

```
C     NEXT, THE 12 DISPOSAL TECHNOLOGY AND 6 SPECTRUM INDICES ARE
C     READ IN THRU INPUT.
C
      READ,IRDC
      READ,(ISPC(J),J=4,9)
      WRITE(2,1010)IRDC $ WRITE(2,1020)(ISPC(J),J=4,9)
      CALL ZERO(DMY,2576) $ CALL RINV(ISPC,NNUC) $ CALL MIN(DMY,14)
C
C     ABOVE SUBROUTINE RINV WAS CALLED TO CALCULATE CONCENTRATIONS
C     WHICH ARE RETURNED IN DMY MATRIX. SUBROUTINE MIN FINDS
C     SMALLEST CONCENTRATION FOR EACH NUCLIDE - OVER ALL 7 ORGANS.
C
C     LOOP 40 CONSIDERS DAUGHTER IN-GROWTH AND PRINTS OUT INTRUDER
C     CONCENTRATIONS TO TAPE2.
C
      DO 40 K=1,14
      A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(17,8,K) $ A2=DMY(23,8,K)*AL240/AL(23)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
      IF(A1.GT.A2) DMY(20,8,K)=A2
      WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
      WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
   40 CONTINUE
      IF(I.NE.-1)GO TO 80
C
C     NEXT SECTION SIMILAR TO ONE ABOVE - ONLY NOW FOR ACCIDENT
C     SCENARIOS.
C
      CALL ZERO(DMY,1840) $ CALL AINV(ISPC,NNUC) $ CALL MIN(DMY,6)
      DO 50 K=1,6
      KK=K+14
      WRITE(2,1003) DES(KK),(ORGAN(J),J=1,8)
      WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
   50 CONTINUE
   80 CONTINUE
 1003 FORMAT(//2X,A9,2X,8A10)
 1004 FORMAT(2X,A10,8E10.2)
 1010 FORMAT(1H1/2X,*DISPOSAL TECHNOLOGY INDICES*/2X
+                *IR =*I2*  ID =*I2*  IC =*I2*  IX =*I2/2X
+                *IE =*I2*  IS =*I2*  IL =*I2*  IG =*I2/2X
+                *IH =*I2*  ICL=*I2*  IPO=*I2*  IIC=*I4)
 1020 FORMAT(/2X*SPECTRAL INDICES*/2X
+                *FLAM  =*I2*   DISP  =*I2/2X
+                *LEACH =*I2*   CHEM  =*I2/2X
+                *STABI =*I2*   ACCES =*I2/)
      STOP $ END
C
C
      SUBROUTINE RINV(ISPC,NNUC)
C
C     THIS ROUTINE DOES MOST OF THE WORK IN CALCULATING THE
C     CONCENTRATIONS. IT IS SIMILAR TO SUBROUTINE RCLAIM IN
C     THE OPTIONS CODE EXCEPT THE PATHWAY EQUATIONS HAVE BEEN
C     MODIFIED TO FIND THE CONCENTRATIONS WHEN THE DOSES ARE
C     GIVEN.
```

<u>Listing for INVERSI Computer Code</u> (continued)

```
C
      COMMON/BAST/DCF(23,7,8)/DTIS/FSC(6),FSA(6)/IMPS/DMY(23,8,14)
+          /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+          /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
      DIMENSION EMP(3),ISPC(11),DLC(7)
      DATA EMP/.5,.75,.5/,DLC/2*500.,1500.,3000.,3*1500./
C
C     THE ABOVE ARRAYS ARE:
C          EMP(3)    : VOLUME EMPLACEMENT EFFICIENCIES
C          ISPC(11) : SPECTRUM INDICES PASSED FROM MAIN PROGRAM
C          DLC(7)    : DOSE LIMITING CRITERIA FOR 7 ORGANS
C
      I5=ISPC(5) $ I6=ISPC(6) $ I7=ISPC(7)
      I8=ISPC(8) $ I9=ISPC(9) $ NSTB=0
      IF(I8.EQ.1.AND.IS.EQ.1)NSTB=1
      A7=1. $ IF(I6.EQ.2.OR.I6.EQ.3) A7=0.80
      IF(I7.EQ.1.OR.IS.EQ.0) I6=I6-1
      FDES=EMP(IE)*(1.-.9*IG)
      A5=1. $ IF(I5.LT.3) A5=10.**(I5-3)
      A6=1. $ IF(I6.GT.1) A6=4.**(1-I6)
      A9=1. $ IF(I9.GT.1) A9=10.**(1-I9)
C
C     OUTSIDE LOOP IN CONCENTRATION CALCULATIONS - SETS UP
C     PARAMETERS NEEDED FOR TESTING WASTE STREAMS AT ALL THREE
C     CLASSIFICATION LEVELS:REGULAR, LAYERED, AND HOT.
C
      DO 50 I3=1,7
      GO TO (11,12,13,14,15,16,17),I3
   11 GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
      A4C=1. $ A4A=1. $ ABC=A7 $ ABA=A7 $ GO TO 20
   12 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      A4C=0.012 $ A4A=0. $ ABC=0.012*A7 $ ABA=0. $ GO TO 20
   13 GDEL=IPO+IIC $ IF(IC.EQ.3) GDEL=IPO+500.
      A4C=0.1 $ A4A=0. $ ABC=A7/1200. $ ABA=0. $ GO TO 20
   14 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      A4C=0.0012 $ A4A=0. $ ABC=0.0012*A7/1200. $ ABA=0. $ GO TO 20
   15 GDEL=IPO+500.
      A4C=1. $ A4A=1. $ ABC=A7 $ ABA=A7 $ GO TO 20
   16 GDEL=IPO+IIC $ IF(IC.EQ.3)GDEL=IPO+500.
      A4C=0.01 $ ABC=0.1*A7/1.44E6 $ IF(IG.EQ.0)ABC=0.1*ABC
      A4A=0. $ ABA=0. $ GO TO 20
   17 GDEL=IPO+1000.
      A4C=1. $ ABC=A7 $ IF(IG.EQ.0)ABC=0.1*ABC
      A4A=1. $ ABA=ABC
C
C     MAIN CALCULATION LOOP
C
   20 DO 40 INUC=1,NNUC
      A1=A9*FDES*FXM(AL(INUC)*GDEL)
      DO 30 I=1,7
      A2=DCF(INUC,I,5)
      B1=A1*A4C*A5*FSC(IR)*DCF(INUC,I,2)
      B2=A1*ABC*A2*0.057
      B3=0.25*A1*A4A*A5*FSA(IR)*DCF(INUC,I,3)
      B4=0.5*0.25*A1*A4A*A6*FMF(INUC)*DCF(INUC,I,4)
```

Listing for INVERSI Computer Code (continued)

```
01770C      B1=A1*A4C*FSC(IR)*DCF(INUC,I,2)
01780C      B3=0.25*A1*A4A*FSA(IR)*DCF(INUC,I,3)
01790C      B4=0.5*0.25*A1*A4A*DCF(INUC,I,4)*FMF(INUC)
01800       B5=0.25*A1*A8A*A2*0.27
01810       J=(I3-1)*2 $ A2=B1+B2 $ A3=B3+B4+B5
01820       IF(A2.NE.0.)DMY(INUC,I,J+1)=DLC(I)/A2
01830       IF(A3.NE.0.)DMY(INUC,I,J+2)=DLC(I)/A3
01840C
01850C      DMY CONTAINS CONCENTRATIONS FOR 2 INTRUDER PATHWAYS
01860C           (J+1) : CONSTRUCTION
01870C           (J+2) : AGRICULTURE
01880C
01890    30 CONTINUE
01900    40 CONTINUE
01910    50 CONTINUE
01920       RETURN $ END
01930C
01940C
01950       SUBROUTINE AINV(ISPC,NNUC)
01960C
01970C      THIS ROUTINE PERFORMS FUNCTION SIMILAR TO THE PRECEDING
01980C      SUBROUTINE - ONLY NOW FOR THE ACCIDENT SCENARIOS.
01990C
02000       COMMON/BAST/DCF(23,7,9)/IMPS/DMY(23,8,10)
02010+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
02020+           /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
02030+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),
02040+           TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
02050       DIMENSION EMP(3),EFF(2),SEFF(2),ISPC(11),
02060+              DLCEA(7),DLCEW(7),DLCAC(7)
02070       DATA EMP/.5,.75,.5/,EFF/6.4,7.0/,SEFF/0.9,0.35/,
02080+          DLCEA/7*100./,DLCEW/7*4./,DLCAC/7*500./
02090C
02100C      THE ABOVE ARRAYS ARE:
02110C           EMP(3)   : VOLUME EMPLACEMENT EFFICIENCIES
02120C           EFF(2)   : LAND USE VOLUME EFFICIENCIES
02130C           SEFF(2)  : LAND USE SURFACE AREA EFFICIENCIES
02140C           ISPC(11) : SPECTRUM INDICES PASSED FROM MAIN PROGRAM
02150C           DLCEA(7) : DOSE LIMITING CRITERIA FOR EROSION AIR
02160C           DLCEW(7) : DOSE LIMITING CRITERIA FOR EROSION WATER
02170C
02180       GREC=IPO+IIC $ GERO=IPO+2000.
02190       IF(IC.EQ.2)GERO=IPO+3000.
02200       IF(IC.EQ.3)GERO=IPO+10000.
02210       AREA=1.8E3*EMP(IE)/4.0
02220C      AREA=200.*EMP(IE)*0.012
02230C      AREA=18.*EMP(IE)/4.0
02240C      AREA=2.*EMP(IE)*0.012
02250C      AREA=0.2*EMP(IE)
02260C
02270C      NEXT SECTION ESTABLISHES AREAL FACTORS FOR 4 EXPOSURE PATHWAYS
02280C
02290       FRA=5.72E-5*POP(IR,1)*AREA   $ VUR=EFF(ID)*1.E-6
02300       FEA=8.09E-6*POP(IR,2)/VUR
02310       FRW=1.15E-4*POP(IR,3)*AREA
02320       FEW=1.15E-4*POP(IR,3)/VUR
02330       I5=ISPC(5) $ A5=1. $ IF(I5.LT.3)A5=10.**(I5-3)
02340       I9=ISPC(9) $ A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
```

```
C
C     MAIN LOOP FOR EXPOSURE CONCENTRATION CALCULATIONS
C
      DO 20 INUC=1,NNUC
      A6=EXM(GREC*AL(INUC)) $ A7=EXM(GERO*AL(INUC))
      DO 10 IORG=1,7
      F1=FRA*A6*DCF(INUC,IORG,8)*A5*A9 $ F2=FEA*A7*DCF(INUC,IORG,8)
      F3=FRW*A6*DCF(INUC,IORG,7)*A5     $ F4=FEW*A7*DCF(INUC,IORG,7)
      IF(F1.NE.0.) DMY(INUC,IORG,1)=DLCEA(IORG)/F1
      IF(F3.NE.0.) DMY(INUC,IORG,3)=DLCEW(IORG)/F3
      IF(F2.NE.0.) DMY(INUC,IORG,2)=DLCEA(IORG)/F2
      IF(F4.NE.0.) DMY(INUC,IORG,4)=DLCEW(IORG)/F4
   10 CONTINUE
   20 CONTINUE
C
C     NEXT SECTION SETS UP PARAMETERS FOR FIRE(FAF) AND SINGLE
C     CONTAINER(FAS) ACCIDENTS.
C
      FAF=TPO(IR,1) $ FAS=TPO(IR,2)
      I6=ISPC(6) $ IF(I6.GT.1) FAS=FAS*(10.**(1-I6))
      I4=ISPC(4) $ IF(I4.LT.3) FAF=FAF*(20.**(I4-3))
      A9=1. $ I9=ISPC(9) $ IF(I9.GT.1)A9=10.**(1-I9)
      IF(IS.EQ.1.AND.I4.NE.3) FAF=0.
C
C     MAIN LOOP FOR ACCIDENT CONCENTRATION CALCULATIONS
C
      DO 70 INUC=1,NNUC
      DO 70 IORG=1,7
C
      A1=A9*FAS*DCF(INUC,IORG,1)
      A2=A9*FAF*DCF(INUC,IORG,1)
      IF(A1.NE.0.) DMY(INUC,IORG,5)=DLCAC(IORG)/A1
      IF(A2.NE.0.) DMY(INUC,IORG,6)=DLCAC(IORG)/A2
   70 CONTINUE
      RETURN $ END
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
C
      FUNCTION EXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      EXM=A2
      RETURN $ END
C
      SUBROUTINE MIN(D,N)
      DIMENSION D(23,8,14),X(7)
      DO 10 I=1,23
      DO 10 K=1,N
      DO 5 J=1,7
      X(J)=D(I,J,K)
      IF(X(J).EQ.0.) X(J)=1.E+99
    5 CONTINUE
      D(I,8,K)=AMIN1(X(1),X(2),X(3),X(4),X(5),X(6),X(7))
   10 CONTINUE
      RETURN $ END
```

Listing for INVERSW Computer Code

```
      PROGRAM INVERSW(INPUT,OUTPUT,TAPE1,TAPE2)
C
C     THIS IS THE INVERSE GROUNDWATER CODE.  IT FINDS INDIVIDUAL
C     NUCLIDE CONCENTRATIONS NECESSARY TO REACH DOSES ASSIGNED IN
C     THE DLC (DOSE LIMITING CRITERIA) STATEMENT.
C
      COMMON/BAST/DCF(23,7,8),FICRP(7)/DTNX/IRDC(12)
+           /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+           /DTIS/FSC(6),FSA(6),PRC(6,2),QFC(6,3),TTM(6,3),TPC(6,3),
+                RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
+           /IMPS/DMY(23,8,5)
C
C     MOST OF THE MATRICES AND ARRAYS ABOVE ARE EXPLAINED IN TABLE H-1.
C     DMY(23,8,5) WILL CONTAIN THE CONCENTRATIONS OUTPUTED FROM
C     SUBROUTINE GINV.
C
      DIMENSION DES(3),ORGAN(8),ISPC(11),LIM(3),CP(3)
      DATA ORGAN/10H   BODY   ,10H   BONE   ,10H   LIVER  ,10H  THYROID ,
+               10H  KIDNEY  ,10H   LUNG   ,10H  GI-LLI  ,10H  MINIMUM
      DATA DES/10H INT-WELL ,10H ROU-WELL ,10H POP-WELL /
      DATA LIM/8H ACTUAL ,8H  LOWER ,8H HIGHER /,CP/1.,.5,4./
C
C     THE ABOVE ARRAYS ARE:
C         DES(3)     : DESCRIPTION OF 3 GROUNDWATER PATHWAYS.
C         ORGAN(8)   : DESCRITION OF 7 ORGAN + A MINIMUM COLUMN.
C         ISPC(11)   : SPECTRUM INDICES READ IN THRU INPUT.
C         LIM(3)     : DESCRIPTION OF 3 RETARDATION LEVELS.
C         CP(3)      : MULTIPLIER USED IN MODIFING RETARDATION LEVEL.
C
      DATA AL240/1.05E-4/
C
C     NEXT SECTION READS IN - THRU TAPE1 - THE NUCLIDE AND
C     REGIONAL DATA NECESSARY FOR THIS PROGRAM.
C
      READ(1,101)NSTR,NNUC,FICRP
      DO 10 I=1,NNUC
      READ(1,104)NUC(I),AL(I),FMF(I),RET(I,1),RET(I,4)
      DO  5 K=1,8
    5 READ(1,106)(DCF(I,J,K),J=1,7)
   10 CONTINUE
      DO 15 I=1,6
      READ(1,105)FSC(I),FSA(I),(PRC(I,J),J=1,2),(QFC(I,J),J=1,3),
+               (TTM(I,J),J=1,3),(TPC(I,J),J=1,3),
+               (RGF(I,J),J=1,3),(POP(I,J),J=1,3),NRET(I),
+               DTTM(I),DTPC(I),(TPO(I,J),J=1,2)
   15 CONTINUE
  101 FORMAT(2I5,7F5.2)
  104 FORMAT(A10,4E10.3)
  105 FORMAT(10X,7E10.3/10X,6E10.3/10X,6E10.3,I5/10X,4F10.3)
  106 FORMAT(10X,7E10.3)
C
C     REMAINING RETARDATION COEFFICIENTS ARE NOW COMPUTED
C
      DO 20 INUC=1,NNUC
      A2=RET(INUC,4) $ A1=(A2/RET(INUC,1))**0.334
      RET(INUC,5)=A2*A1 $ RET(INUC,3)=A2/A1
   20 RET(INUC,2)=RET(INUC,1)*A1
```

Listing for INVERSW Computer Code (continued)

```
C
C     THE 12 DISPOSAL TECHNOLOGY INDICES AND 6 NECESSARY SPECTRUM
C     INDICES ARE READ IN THRU INPUT.
C
      READ,IRDC $ READ,(ISPC(J),J=4,9)
      WRITE(2,1010)IRDC $ WRITE(2,1020)(ISPC(J),J=4,9)
C
C     LOOP 35 FINDS THE GROUNDWATER CONCENTRATIONS FOR EACH OF
C     THE 5 RETARDATION COEFFICIENTS. SUBROUTINE GINV DOES MOST OF
C     CALCULATIONS INVOLVED. DAUGHTER IN-GROWTH IS ALSO TAKEN
C     INTO CONSIDERATION.
C
      DO 35 IRET=1,5
      WRITE(2,1005) IRET $ CALL ZERO(DMY,920)
      CALL GINV(ISPC,NNUC,IRET) $ CALL MIN(DMY,3)
      DO 30 K=1,3
      A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(17,8,K) $ A2=DMY(23,8,K)*AL240/AL(23)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
      IF(A1.GT.A2) DMY(20,8,K)=A2
      WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
      WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
   30 CONTINUE
   35 CONTINUE
C
   40 IR=IRDC(1) $ NR=NRET(IR)
C
C     LOOP 60 FINDS THE GROUNDWATER CONCENTRATIONS FOR THE
C     RETARDATION COEFFICIENT AS IMPLIED BY THE IR INDEX OF
C     DISPOSAL TECHNOLOGY. THIS LOOP HOWEVER VARIES THE PERCOLATION
C     VALUE. IT USES THE VALUE IMPLIED BY IR AS WELL AS HALF THIS
C     VALUE AND DOUBLE THIS VALUE.
C
      DO 60 KN=1,3
      A1=DMY(17,8,K) $ A2=DMY(22,8,K)*AL(17)/AL(22)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(17,8,K) $ A2=DMY(23,8,K)*AL240/AL(23)
      IF(A1.GT.A2) DMY(17,8,K)=A2
      A1=DMY(20,8,K) $ A2=DMY(18,8,K)*AL(20)/AL(18)
      IF(A1.GT.A2) DMY(20,8,K)=A2
      WRITE(2,1006) LIM(KN) $ CALL ZERO(DMY,920)
      PRC(IR,1)=PRC(IR,1)*CP(KN) $ PRC(IR,2)=PRC(IR,2)*CP(KN)
      CALL GINV(ISPC,NNUC,NR) $ CALL MIN(DMY,3)
      DO 50 K=1,3
      WRITE(2,1003) DES(K),(ORGAN(J),J=1,8)
      WRITE(2,1004)(NUC(I),(DMY(I,J,K),J=1,8),I=1,NNUC)
   50 CONTINUE
   60 CONTINUE
C
 1001 FORMAT(12I3)
 1003 FORMAT(//2X,A9,8A10)
 1004 FORMAT(A10,8E10.2)
 1005 FORMAT(//2X,*RETARDATION COEFF. *,I2)
 1006 FORMAT(//2X,A7,*PERCOLATION VALUE*)
```

Listing for INVERSW Computer Code (continued)

```
 1010 FORMAT(2X,*DISPOSAL TECHNOLOGY INDICES*/2X,
+               *IR =*,I2,*  ID =*,I2,*  IC =*,I2,*  IX =*,I2/2X,
+               *IE =*,I2,*  IS =*,I2,*  IL =*,I2,*  IG =*,I2/2X,
+               *IH =*,I2,*  ICL=*,I2,*  IPO=*,I2,*  IIC=*,I4)
 1020 FORMAT(/2X,*SPECTRAL INDICES*/2X,
+               *FLAM  =*,I2,*   DISP  =*,I2/2X,
+               *LEACH =*,I2,*   CHEM  =*,I2/2X,
+               *STABI =*,I2,*   ACCES =*,I2)
      STOP $ END
C
C
      SUBROUTINE GINV(ISPC,NNUC,NRT)
C
C     THIS ROUTINE CONTAINS THE ACTUAL CALCULATION OF THE
C     CONCENTRATIONS.
C
      COMMON/BAST/DCF(23,7,8)/IMPS/DMY(23,8,5)
+          /NUCS/NUC(23),AL(23),FMF(23),RET(23,5)
+          /DTNX/IR,ID,IC,IX,IE,IS,IL,IG,IH,ICL,IPO,IIC
+          /DTIS/FSC(6),FSA(6),PRC(6,2),OFC(6,3),TTM(6,3),
+          TPC(6,3),RGF(6,3),POP(6,3),DTTM(6),DTPC(6),TPO(6,2),NRET(6)
      DIMENSION EMP(3),EFF(2),SEFF(2),DLC(7,3),ISPC(11)
      DATA NSEC/10/,DLC/2*500.,1500.,3000.,3*1500.,3*25.,75.,3*25.,7*4./
      DATA EMP/.5,.75,.5/,EFF/6.4,7.0/,SEFF/0.9,0.35/
C
C     THE MATRICES AND ARRAYS ABOVE ARE:
C          EMP(3)     : VOLUME EMPLACEMENT EFFICIENCIES
C          EFF(2)     : LAND USE VOLUME EFFICIENCIES
C          SEFF(2)    : LAND USE SURFACE AREA EFFICIENCIES
C          DLC(7,3)   : DOSE LIMITING CRITERIA FOR 7 ORGANS
C                       AND 3 PATHWAYS.
C                       PARTITIONED INTO.
C
      GDEL=0. $ VUR=1.0/(EMP(IE)*EFF(ID))
      IF(IC.EQ.1)PRCD=PRC(IR,1)
      IF(IC.GT.1)PRCD=PRC(IR,2)
      IF(IX.EQ.1)PRCD=4.*PRC(IR,1)
      IF(IX.GT.1)PRCD=2.25*PRCD
      I6=ISPC(6) $ I7=ISPC(7) $ I8=ISPC(8) $ I9=ISPC(9)
      PERC=PRCD $ IF(IS.EQ.0.OR.I7.EQ.1)I6=I6-1
      IF(I8.NE.1.OR.IS.NE.1)GO TO 20
      IF(IC.EQ.1)PERC=PRC(IR,1)
      IF(IC.GT.1)PERC=PRC(IR,2)
   20 TVOL=[illegible]2000.*SQRT(PRC(IR,1)*27.8)
      IF(IL.EQ.2.OR.IH.EQ.1)PERC=PRC(IR,2)/16.
      PERC=PERC*(1.0-0.9*IG)
      A6=1. $ IF(I6.GT.1)A6= 4.**(1-I6)
      A9=1. $ IF(I9.GT.1)A9=10.**(1-I9)
      I1=NRT $ IF(IS.EQ.0.OR.I7.EQ.1)I1=I1-1
      TDUM=1.0/(PERC*VUR*A6*A9) $ IF(I1.LE.0)I1=1
C
```

```
C     MAIN LOOP - GROUNDWATER PATHWAY EQUATIONS MANIPULATED SO
C                 AS TO FIND CONCENTRATIONS WHEN THE DOSE IS GIVEN.
C
      DO 80 INUC=1,NNUC
      TDUR=TDUM/FMF(INUC)
      DO 70 IPTH=1,3
      I2=6 $ IF(IPTH.EQ.3) I2=7
      B2=RGF(IR,IPTH)/(QFC(IR,IPTH)*NSEC*TDUR)
      IF(TVOL.GT.QFC(IR,IPTH))B2=B2*QFC(IR,IPTH)/TVOL
      A3=0. $ TNRT=RET(INUC,I1)*TTM(IR,IPTH)
      DO 40 ISEC=1,NSEC
      B3=TNRT+RET(INUC,I1)*(ISEC-1)*DTTM(IR)
      IF(B3.GE.TNRT+TDUR)GO TO 50
      A4=ISEC*EXM(AL(INUC)*B3)
      A3=AMAX1(A3,A4)
   40 CONTINUE
   50 DO 60 IORG=1,7
      AD=1.E6*A3*B2*DCF(INUC,IORG,I2)
      A1=0. $ IF(AD.NE.0.) A1=DLC(IORG,IPTH)/AD
   60 DMY(INUC,IORG,IPTH)=A1
   70 CONTINUE
   80 CONTINUE
      RETURN $ END
C
C
      SUBROUTINE ZERO(A,N)
      DIMENSION A(N)
      DO 10 I=1,N
   10 A(I)=0.
      RETURN $ END
C
      FUNCTION EXM(A1)
      A2=0. $ IF(A1.LT.230.)A2=EXP(-A1)
      EXM=A2
      RETURN $ END
C
      SUBROUTINE MIN(D,N)
C
C     THIS ROUTINE RETURNS THE SMALLEST CONCENTRATION - OVER
C     ALL 7 ORGANS - FOR EACH NUCLIDE.
C
      DIMENSION D(23,8,5),X(7)
      DO 10 I=1,23
      DO 10 K=1,N
      DO 5 J=1,7
      X(J)=D(I,J,K)
      IF(X(J).EQ.0.) X(J)=1.E+99
    5 CONTINUE
      D(I,8,K)=AMIN1(X(1),X(2),X(3),X(4),X(5),X(6),X(7))
   10 CONTINUE
      RETURN $ END
```

Listing of DATA Data File

```
  36   231.000 .120 .060 .030 .060 .120 .060
P-IXRESIN 1.100E-01 3.463E+04
        1 3.360E-02 2.660E-03 9.740E-05 2.340E-03 2.790E-06 4.530E-03
        1 8.610E-04 8.840E-08 1.940E-04 8.230E-07 2.440E-06 8.230E-07
        1 2.190E-02 4.710E-08 3.710E-07 9.060E-12 2.600E-05 1.820E-05
        1 7.940E-04 3.990E-08 4.154E-05 1.260E-06 9.920E-09 1.380E-05
P-CONCLIQ 1.100E-01 2.435E+05
        2 1.090E-01 3.450E-03 1.270E-04 2.270E-02 2.710E-05 4.400E-02
        2 8.360E-03 8.580E-07 2.520E-04 1.070E-06 3.160E-06 1.070E-06
        2 2.850E-02 6.150E-08 4.840E-07 1.180E-11 5.120E-05 3.310E-05
        2 1.440E-03 7.250E-08 7.132E-05 2.020E-06 1.170E-08 1.920E-05
P-FSLUDGE 1.100E-01 4.279E+03
        3 1.060E+00 2.590E-03 9.550E-05 3.100E-01 3.710E-04 6.000E-01
        3 1.140E-01 1.170E-05 1.890E-04 8.030E-07 2.370E-06 8.030E-07
        3 2.140E-02 1.460E-07 1.150E-06 2.810E-11 4.760E-05 1.550E-04
        3 6.750E-03 3.390E-07 4.581E-04 1.780E-05 3.100E-07 1.770E-04
P-FCARTRG 1.100E-01 2.177E+04
        4 1.860E+00 1.150E-03 4.250E-05 5.550E-01 6.600E-04 1.070E+00
        4 2.040E-01 2.090E-05 8.400E-05 3.580E-07 1.060E-06 3.580E-07
        4 9.540E-03 3.640E-07 2.870E-06 7.020E-11 2.510E-04 3.800E-04
        4 1.660E-02 3.340E-07 6.414E-04 1.100E-05 1.930E-07 1.100E-04
B-IXRESIN 1.200E-01 7.623E+04
        5 4.630E+00 1.920E-02 1.190E-03 9.480E-01 9.800E-04 1.590E+00
        5 2.150E-02 3.090E-05 3.640E-03 7.650E-05 2.040E-04 7.650E-05
        5 2.040E+00 5.330E-08 4.200E-07 1.020E-11 8.340E-05 5.340E-05
        5 2.600E-03 1.170E-07 9.798E-05 1.570E-06 2.700E-08 1.820E-05
B-CONCLIQ 1.200E-01 2.102E+05
        6 2.870E-01 6.240E-04 3.890E-05 7.940E-02 8.210E-05 1.330E-01
        6 1.800E-03 2.590E-06 1.180E-04 2.500E-06 6.650E-06 2.500E-06
        6 6.650E-02 3.440E-08 2.710E-07 6.610E-12 1.990E-04 9.430E-05
        6 4.600E-03 2.060E-07 2.523E-04 8.100E-06 2.590E-07 2.050E-04
B-FSLUDGE 1.200E-01 1.690E+05
        7 5.240E+00 1.260E-02 7.780E-04 1.440E+00 1.490E-03 2.410E+00
        7 3.250E-02 4.700E-05 2.370E-03 5.000E-05 1.330E-04 5.000E-05
        7 1.330E+00 3.320E-07 2.610E-06 6.380E-11 4.660E-04 2.360E-04
        7 1.150E-02 5.180E-07 4.868E-04 1.050E-05 2.970E-07 2.240E-04
P-COTRASH 2.100E-01 4.244E+05
        8 2.280E-02 3.040E-04 1.120E-05 5.970E-03 7.110E-06 1.150E-02
        8 2.190E-03 2.250E-07 2.220E-05 9.420E-08 2.780E-07 9.420E-08
        8 2.510E-03 7.890E-09 6.220E-08 1.520E-12 5.970E-06 5.530E-06
        8 2.410E-04 1.210E-08 1.089E-05 2.670E-07 2.740E-09 2.610E-06
P-NCTRASH 2.100E-01 2.178E+05
        9 5.250E-01 6.990E-03 2.570E-04 1.370E-01 1.640E-04 2.650E-01
        9 5.050E-02 5.180E-06 5.110E-04 2.170E-06 6.410E-06 2.170E-06
        9 5.780E-02 1.820E-07 1.430E-06 3.490E-11 1.380E-04 1.270E-04
        9 5.550E-03 2.790E-07 2.508E-04 6.150E-06 6.300E-08 6.000E-05
B-COTRASH 2.200E-01 2.086E+05
       10 2.350E-02 6.750E-05 4.170E-06 6.010E-03 6.210E-06 1.010E-02
       10 1.360E-04 1.960E-07 1.270E-05 2.680E-07 7.140E-07 2.680E-07
       10 7.140E-03 1.220E-09 9.600E-09 2.350E-13 2.300E-06 1.160E-06
       10 5.630E-05 2.530E-09 2.586E-06 6.520E-08 1.930E-09 1.490E-06
B-NCTRASH 2.200E-01 9.896E+04
       11 3.790E+00 1.090E-02 6.730E-04 9.690E-01 1.000E-03 1.620E+00
       11 2.190E-02 3.160E-05 2.050E-03 4.330E-05 1.150E-04 4.330E-05
       11 1.150E+00 1.970E-07 1.550E-06 3.780E-11 3.710E-04 1.860E-04
       11 9.080E-03 4.080E-07 4.172E-04 1.050E-05 3.120E-07 2.410E-04
F-COTRASH 2.110E-01 2.359E+05
       12 5.580E-06        0.        0.        0.        0.        0.
       12        0.        0.        0.        0.        0.        0.
       12        0. 1.180E-06 4.400E-06        0.        0.        0.
       12        0.        0.        0.        0.        0.        0.
F-NCTRASH 2.110E-01 4.171E+04
       13 5.330E-06        0.        0.        0.        0.        0.
       13        0.        0.        0.        0.        0.        0.
       13        0. 1.130E-06 4.200E-06        0.        0.        0.
       13        0.        0.        0.        0.        0.        0.
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Listing of DATA Data File (Continued)

```
       ..         ..          ..          ..          ..          ..          ..
I-COTRASH 2.030E-01 1.407E+05
       14 1.130E-01 9.130E-02 5.260E-03     0.          0.      1.040E-02
       14     0.        0.    1.450E-03 3.390E-09       0.          0.
       14 4.560E-03     0.        0.        0.          0.          0.
       14     0.        0.    4.820E-06     0.          0.          0.
I+COTRASH.2.030E-01 1.407E+05
       15 1.130E-01 9.130E-02 5.260E-03     0.          0.      1.040E-02
       15     0.        0.    1.450E-03 3.390E-09       0.          0.
       15 4.560E-03     0.        0.        0.          0.          0.
       15     0.        0.    4.820E-06     0.          0.          0.
N-SSTRASH 2.060E-01 1.796E+05
       16 1.120E-05     0.        0.        0.          0.          0.
       16     0.        0.        0.        0.          0.          0.
       16     0.    2.360E-06 8.800E-06     0.          0.          0.
       16     0.        0.        0.        0.          0.          0.
N+SSTRASH 2.060E-01 1.796E+05
       17 1.120E-05     0.        0.        0.          0.          0.
       17     0.        0.        0.        0.          0.          0.
       17     0.    2.360E-06 8.800E-06     0.          0.          0.
       17     0.        0.        0.        0.          0.          0.
N-LOTRASH 2.070E-01 5.064E+04
       18 3.530E-02 2.850E-02 1.640E-03     0.          0.      3.250E-03
       18     0.        0.    4.530E-04 1.060E-09       0.          0.
       18 1.420E-03     0.        0.        0.          0.          0.
       18     0.        0.    1.510E-06     0.          0.          0.
N+LOTRASH 2.070E-01 5.064E+04
       19 3.530E-02 2.350E-02 1.640E-03     0.          0.      3.250E-03
       19     0.        0.    4.530E-04 1.060E-09       0.          0.
       19 1.420E-03     0.        0.        0.          0.          0.
       19     0.        0.    1.510E-06     0.          0.          0.
F-PROCESS 3.110E-01 7.816E+04
       20 1.080E-04     0.        0.        0.          0.          0.
       20     0.        0.        0.        0.          0.          0.
       20     0.    2.300E-05 8.540E-05     0.          0.          0.
       20     0.        0.        0.        0.          0.          0.
U-PROCESS 3.120E-01 2.811E+04
       21 3.800E-04     0.        0.        0.          0.          0.
       21     0.        0.        0.        0.          0.          0.
       21     0.    1.650E-05 3.640E-04     0.          0.          0.
       21     0.        0.        0.        0.          0.          0.
I-LQSCNVL 3.030E-01 4.914E+04
       22 9.600E-03 5.010E-03 2.510E-04     0.          0.          0.
       22     0.        0.    4.340E-03     0.          0.          0.
       22     0.        0.        0.        0.          0.          0.
       22     0.        0.        0.        0.          0.          0.
I+LQSCNVL 3.030E-01 4.914E+04
       23 9.600E-03 5.010E-03 2.510E-04     0.          0.          0.
       23     0.        0.    4.340E-03     0.          0.          0.
       23     0.        0.        0.        0.          0.          0.
       23     0.        0.        0.        0.          0.          0.
I-ABSLIQD 3.030E-01 5.585E+03
       24 1.990E-01 1.420E-01 8.160E-03     0.          0.      3.120E-02
       24     0.        0.    4.340E-03 1.020E-08       0.          0.
       24 1.370E-02     0.        0.        0.          0.          0.
       24     0.        0.        0.        0.          0.          0.
I+ABSLIQD 3.030E-01 5.585E+03
       25 1.990E-01 1.420E-01 8.160E-03     0.          0.      3.120E-02
       25     0.        0.    4.340E-03 1.020E-08       0.          0.
       25 1.370E-02     0.        0.        0.          0.          0.
       25     0.        0.        0.        0.          0.          0.
I-BIOWAST 3.030E-01 1.571E+04
       26 2.060E-01 1.750E-01 1.010E-02     0.          0.      3.990E-03
       26     0.        0.    8.330E-03 6.510E-09       0.          0.
       26 8.760E-03     0.        0.        0.          0.          0.
       26     0.        0.        0.        0.          0.          0.
I+BIOWAST 3.030E-01 1.571E+04
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Listing of DATA Data File (Continued)

```
         27 2.060E-01 1.750E-01 1.010E-02     0.          0.     3.990E-03
         27     0.        0.    8.330E-03 6.510E-09     0.          0.
         27 8.760E-03     0.        0.        0.          0.          0.
         27     0.        0.        0.        0.          0.          0.
N-SSWASTE 3.060E-01 6.339E+04
         28 2.170E-04     0.        0.        0.          0.          0.
         28     0.        0.        0.        0.          0.          0.
         28     0.    4.600E-05 1.710E-04     0.          0.          0.
         28     0.        0.        0.        0.          0.          0.
N-LOWASTE 3.070E-01 6.027E+04
         29 2.110E-02 1.630E-02 9.360E-04     0.          0.     1.470E-03
         29     0.        0.    1.310E-03 7.760E-10     0.          0.
         29 1.040E-03     0.        0.        0.          0.          0.
         29     0.        0.        0.        0.          0.          0.
L-NFRCOMP 4.300E-01 2.887E+03
         30 4.040E+03     0.    2.590E-01 2.230E+03 1.400E+00 1.600E+03
         30 2.090E+02 8.190E-03     0.        0.          0.          0.
         30     0.        0.        0.        0.          0.          0.
         30     0.        0.        0.        0.          0.          0.
L-DECONRS 4.400E-01 3.478E+04
         31 1.560E+02 1.080E-02 6.880E-04 4.050E+01 4.490E-02 7.280E+01
         31 3.690E+00 1.420E-03 4.280E-02 1.200E-05 3.340E-05 1.200E-05
         31 3.190E-01 6.840E-05 5.400E-04 1.320E-08 1.340E+00 1.770E+00
         31 3.550E+01 3.870E-03 1.026E+00 3.590E-04 3.460E-04 3.270E-03
N-ISOPROD 4.040E-01 5.196E+03
         32 1.500E+01 4.200E-02 4.510E-05     0.          0.          0.
         32     0.        0.    6.270E+00 3.270E-04 2.720E-06 3.270E-04
         32 8.730E+00 1.020E-05 3.810E-05 5.330E-13 1.970E-04 5.550E-05
         32 7.100E-03 9.570E-08 2.152E-04 1.250E-06 1.650E-04 2.880E-07
N-HIGMACT 4.030E-01 2.608E+03
         33 2.100E+02     0.    1.320E-02 1.150E+02 6.560E-02 8.480E+01
         33 1.060E+01 4.470E-04     0.        0.          0.          0.
         33     0.        0.        0.        0.          0.          0.
         33     0.        0.        0.        0.          0.          0.
N-TRITIUM 4.050E-01 3.481E+03
         34 2.330E+03 2.330E+03     0.        0.          0.          0.
         34     0.        0.        0.        0.          0.          0.
         34     0.        0.        0.        0.          0.          0.
         34     0.        0.        0.        0.          0.          0.
N-SOURCES 4.030E-01 1.865E+02
         35 5.760E+03 2.090E+03 3.190E-03     0.          0.     8.120E+01
         35 1.050E+01     0.    2.870E+01     0.          0.          0.
         35 3.540E+03     0.        0.        0.          0.          0.
         35     0.        0.    1.600E+01     0.          0.          0.
N-TARGETS 4.030E-01 1.340E+03
         36 8.040E+01 8.040E+01     0.        0.          0.          0.
         36     0.        0.        0.        0.          0.          0.
         36     0.        0.        0.        0.          0.          0.
         36     0.        0.        0.        0.          0.          0.
H-3         5.630E-02 1.150E+00 1.000E+00 1.000E+00
H-3    /ACC 1.252E+09 5.190E+07 1.252E+09 1.252E+09 1.252E+09 1.252E+09 5.190E+07
H-3    /CON 1.172E+10 5.190E+07 1.172E+10 1.172E+10 1.172E+10 1.172E+10 1.052E+10
H-3    /AGR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
H-3    /FOO 5.995E+04     0.    5.995E+04 5.995E+04 5.995E+04 5.995E+04 5.995E+04
H-3    /DGM     0.        0.        0.        0.        0.        0.        0.
H-3    /WWT 2.367E+06 1.422E-01 2.367E+06 2.367E+06 2.367E+06 2.367E+06 2.367E+06
H-3    /SWT 2.368E+06 1.422E-01 2.368E+06 2.368E+06 2.368E+06 2.368E+06 2.368E+06
H-3    /AIR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
C-14        1.210E-04 5.760E-03 1.000E+01 1.000E+01
C-14   /ACC 3.166E+09 1.405E+10 3.166E+09 3.166E+09 3.166E+09 3.166E+09 2.526E+09
C-14   /CON 6.678E+10 3.321E+11 6.678E+10 6.678E+10 6.678E+10 6.678E+10 6.614E+10
C-14   /AGR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
C-14   /FOO 3.721E+05 1.861E+06 3.721E+05 3.721E+05 3.721E+05 3.721E+05 3.721E+05
C-14   /DGM     0.        0.        0.        0.        0.        0.        0.
C-14   /WWT 1.441E+07 7.205E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07
C-14   /SWT 3.761E+07 1.880E+08 3.761E+07 3.761E+07 3.761E+07 3.761E+07 3.761E+07
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Listing of DATA Data File (Continued)

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C-14  /AIR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
FE-55      2.670E-01 1.480E-02 6.300E+02 5.400E+03
FE-55 /ACC 1.805E+10 1.885E+10 2.413E+10 1.613E+10 1.613E+10 2.081E+11 1.925E+10
FE-55 /CON 9.283E+09 4.816E+10 3.941E+10 5.080E+07 5.080E+07 2.095E+11 2.116E+10
FE-55 /AGR 3.219E+10 1.903E+11 1.376E+11 5.080E+07 5.080E+07 2.644E+11 7.752E+10
FE-55 /FOO 3.482E+01 2.161E+02 1.493E+02    0.        0.     8.331E+01 8.566E+01
FE-55 /DGM    0.        0.        0.        0.        0.        0.        0.
FE-55 /WWT 2.727E+06 1.244E+07 8.863E+06 8.609E+05 8.609E+05 5.326E+06 5.452E+06
FE-55 /SWT 4.450E+06 2.314E+07 1.625E+07 8.609E+05 8.609E+05 9.449E+06 9.692E+06
FE-55 /AIR 4.827E+10 2.054E+11 1.537E+11 1.613E+10 1.613E+10 2.804E+11 9.360E+10
NI-59      8.660E-06 1.480E-02 4.200E+02 3.600E+03
NI-59 /ACC 3.698E+10 9.378E+10 5.058E+10 2.578E+10 2.578E+10 5.778E+10 2.850E+10
NI-59 /CON 3.872E+10 2.325E+11 8.130E+10 5.980E+07 5.980E+07 3.206E+10 1.441E+10
NI-59 /AGR 1.247E+11 7.476E+11 2.581E+11 5.980E+07 5.980E+07 3.206E+10 5.082E+10
NI-59 /FOO 3.693E+03 2.211E+04 7.590E+03    0.        0.        0.     1.563E+03
NI-59 /DGM 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03
NI-59 /WWT 8.537E+06 4.425E+07 1.609E+07 1.377E+06 1.377E+06 1.377E+06 4.408E+06
NI-59 /SWT 9.825E+06 5.196E+07 1.874E+07 1.377E+06 1.377E+06 1.377E+06 4.953E+06
NI-59 /AIR 1.505E+11 7.733E+11 2.838E+11 2.578E+10 2.578E+10 5.778E+10 7.654E+10
CO-60      1.320E-01 1.480E-02 4.200E+02 3.600E+03
CO-60 /ACC 2.358E+12 2.336E+12 2.353E+12 2.336E+12 2.336E+12 2.634E+13 2.504E+12
CO-60 /CON 1.237E+11 2.280E+10 7.599E+10 2.280E+10 2.280E+10 2.402E+13 8.593E+11
CO-60 /AGR 3.695E+11 2.280E+10 1.874E+11 2.280E+10 2.280E+10 2.402E+13 2.953E+12
CO-60 /FOO 5.274E+03    0.     2.391E+03    0.        0.        0.     4.492E+04
CO-60 /DGM 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07
CO-60 /WWT 1.432E+08 1.238E+08 1.326E+08 1.238E+08 1.238E+08 1.239E+08 2.893E+08
CO-60 /SWT 1.458E+08 1.238E+08 1.338E+08 1.238E+08 1.238E+08 1.239E+08 3.112E+08
CO-60 /AIR 2.683E+12 2.336E+12 2.500E+12 2.336E+12 2.336E+12 2.634E+13 5.266E+12
NI-63      7.530E-03 1.480E-02 4.200E+02 3.600E+03
NI-63 /ACC 3.056E+10 9.602E+11 6.576E+10 1.560E+08 1.560E+08 8.816E+10 7.436E+09
NI-63 /CON 1.040E+11 3.150E+12 2.176E+11 1.560E+08 1.560E+08 8.816E+10 3.911E+10
NI-63 /AGR 3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NI-63 /FOO 9.878E+03 2.945E+05 2.041E+04    0.        0.        0.     4.259E+03
NI-63 /DGM    0.        0.        0.        0.        0.        0.        0.
NI-63 /WWT 1.915E+07 5.711E+08 3.958E+07 4.276E-01 4.276E-01 2.416E+02 8.258E+06
NI-63 /SWT 2.260E+07 6.738E+08 4.670E+07 4.276E-01 4.276E-01 2.416E+02 9.743E+06
NI-63 /AIR 3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NB-94      3.470E-05 1.110E-02 1.000E+03 1.000E+04
NB-94 /ACC 6.102E+11 6.114E+11 6.108E+11 6.095E+11 6.107E+11 1.330E+12 6.839E+11
NB-94 /CON 1.389E+10 1.515E+10 1.454E+10 1.320E+10 1.446E+10 7.332E+11 4.432E+11
NB-94 /AGR 1.399E+10 1.548E+10 1.472E+10 1.320E+10 1.464E+10 7.332E+11 1.557E+12
NB-94 /FOO 2.116E+00 7.078E+00 3.937E+00    0.     3.892E+00    0.     2.390E+04
NB-94 /DGM 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+05
NB-94 /WWT 3.193E+07 3.196E+07 3.194E+07 3.192E+07 3.194E+07 3.192E+07 1.466E+08
NB-94 /SWT 3.232E+07 3.324E+07 3.266E+07 3.192E+07 3.265E+07 3.192E+07 4.496E+09
NB-94 /AIR 6.103E+11 6.118E+11 6.111E+11 6.095E+11 6.110E+11 1.330E+12 2.153E+12
SR-90      2.470E-02 9.860E-03 9.000E+00 7.300E+01
SR-90 /ACC 2.417E+13 9.617E+13 1.668E+11 1.668E+11 1.668E+11 1.980E+11 1.892E+11
SR-90 /CON 6.394E+13 2.588E+14 1.760E+09 1.760E+09 1.760E+09 3.296E+10 4.727E+12
SR-90 /AGR 1.891E+14 7.686E+14 1.760E+09 1.760E+09 1.760E+09 3.296E+10 1.946E+13
SR-90 /FOO 6.407E+07 2.611E+08    0.        0.        0.        0.     7.543E+06
SR-90 /DGM 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04
SR-90 /WWT 9.564E+09 3.895E+10 8.835E+06 8.835E+06 8.835E+06 8.835E+06 1.134E+09
SR-90 /SWT 1.014E+10 4.128E+10 8.835E+06 8.835E+06 8.835E+06 8.835E+06 1.201E+09
SR-90 /AIR 1.892E+14 7.688E+14 1.668E+11 1.668E+11 1.668E+11 1.980E+11 1.962E+13
TC-99      3.270E-06 1.150E-01 2.000E+00 5.000E+00
TC-99 /ACC 1.176E+09 9.680E+08 2.280E+09 7.600E+08 1.996E+10 7.400E+09 7.880E+09
TC-99 /CON 2.960E+09 5.411E+09 8.890E+09 7.600E+08 1.031E+11 7.962E+09 2.240E+11
TC-99 /AGR 8.548E+09 1.933E+10 2.960E+10 7.600E+08 3.636E+11 9.720E+09 9.008E+11
TC-99 /FOO 6.566E+03 1.635E+04 2.433E+04    0.     3.061E+05 2.067E+03 7.953E+05
TC-99 /DGM    0.        0.        0.        0.        0.        0.        0.
TC-99 /WWT 4.186E+05 1.042E+06 1.551E+06 2.083E+00 1.951E+07 1.318E+05 5.069E+07
TC-99 /SWT 4.240E+05 1.056E+06 1.571E+06 2.083E+00 1.976E+07 1.335E+05 5.135E+07
TC-99 /AIR 8.548E+09 1.933E+10 2.960E+10 7.600E+08 3.636E+11 9.721E+09 9.008E+11
I-129      4.080E-08 1.150E-01 2.000E+00 5.000E+00
I-129 /ACC 9.139E+11 8.515E+11 8.515E+11 5.128E+13 8.515E+11 8.572E+11 8.521E+11
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Listing of DATA Data File (Continued)

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I-129 /CON 2.068E+12 7.124E+11 6.123E+11 1.624E+15 1.315E+12 6.366E+09 9.787E+10
I-129 /AGR 8.346E+12 2.942E+12 2.528E+12 6.553E+15 5.433E+12 6.366E+09 4.006E+11
I-129 /FOO 6.019E+04 2.137E+04 1.836E+04 4.725E+07 3.947E+04    0.     2.901E+03
I-129 /DGM 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04
I-129 /WWT 4.299E+07 1.758E+07 1.562E+07 3.091E+10 2.938E+07 3.644E+06 5.536E+06
I-129 /SWT 4.389E+07 1.793E+07 1.592E+07 3.160E+10 3.004E+07 3.644E+06 5.594E+06
I-129 /AIR 9.197E+12 3.792E+12 3.379E+12 6.554E+15 6.284E+12 8.572E+11 1.251E+12
CS-135     2.310E-07 1.620E-04 8.500E+01 7.200E+02
CS-135/ACC 2.371E+10 9.651E+10 8.851E+10 5.080E+08 3.331E+10 1.491E+10 1.004E+09
CS-135/CON 1.566E+11 4.209E+11 3.879E+11 5.080E+08 1.466E+11 4.884E+10 8.007E+09
CS-135/AGR 5.729E+11 1.437E+12 1.326E+12 5.080E+08 5.014E+11 1.551E+11 2.994E+10
CS-135/FOO 8.836E+03 2.157E+04 1.991E+04    0.     7.531E+03 2.256E+03 4.656E+02
CS-135/DGM    0.        0.        0.        0.        0.        0.        0.
CS-135/WWT 3.318E+07 8.098E+07 7.475E+07 1.392E+00 2.828E+07 8.472E+06 1.748E+06
CS-135/SWT 1.442E+08 3.520E+08 3.250E+08 1.392E+00 1.229E+08 3.683E+07 7.600E+06
CS-135/AIR 5.729E+11 1.437E+12 1.326E+12 5.080E+08 5.014E+11 1.551E+11 2.994E+10
CS-137     2.310E-02 1.620E-04 8.500E+01 7.200E+02
CS-137/ACC 4.499E+11 6.339E+11 7.779E+11 2.419E+11 4.259E+11 3.299E+11 2.444E+11
CS-137/CON 1.397E+12 1.719E+12 2.351E+12 1.530E+09 9.010E+11 2.941E+11 3.919E+10
CS-137/AGR 5.117E+12 5.872E+12 8.030E+12 1.530E+09 2.729E+12 9.350E+11 1.491E+11
CS-137/FOO 7.896E+04 8.814E+04 1.205E+05    0.     4.092E+04 1.360E+04 2.333E+03
CS-137/DGM 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06
CS-137/WWT 3.094E+08 3.438E+08 4.655E+08 1.287E+07 1.665E+08 6.394E+07 2.163E+07
CS-137/SWT 1.302E+09 1.452E+09 1.981E+09 1.287E+07 6.808E+08 2.349E+08 5.096E+07
CS-137/AIR 5.358E+12 6.112E+12 8.270E+12 2.419E+11 2.969E+12 1.175E+12 3.895E+11
U-235      9.750E-10 1.250E-04 8.400E+02 7.200E+03
U-235 /ACC 2.062E+12 3.062E+13 2.214E+11 2.214E+11 7.262E+12 3.360E+15 5.175E+11
U-235 /CON 2.643E+12 4.361E+13 1.590E+09 1.590E+09 1.013E+13 3.360E+15 1.586E+12
U-235 /AGR 5.154E+12 6.500E+13 1.590E+09 1.590E+09 1.979E+13 3.360E+15 5.621E+12
U-235 /FOO 1.443E+04 2.378E+05    0.        0.     5.552E+04    0.     2.319E+04
U-235 /DGM 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05
U-235 /WWT 2.073E+08 3.235E+09 1.177E+07 1.177E+07 7.643E+08 2.098E+07 3.261E+08
U-235 /SWT 2.109E+08 3.294E+09 1.177E+07 1.177E+07 7.781E+08 2.098E+07 3.318E+08
U-235 /AIR 5.374E+12 8.522E+13 2.214E+11 2.214E+11 2.001E+13 3.360E+15 5.841E+12
U-238      1.540E-10 1.250E-04 8.400E+02 7.200E+03
U-238 /ACC 1.695E+12 2.882E+13 1.454E+10 1.454E+10 6.575E+12 3.120E+15 2.546E+11
U-238 /CON 2.429E+12 4.145E+13 8.570E+07 8.570E+07 9.447E+12 3.120E+15 1.147E+12
U-238 /AGR 4.774E+12 6.108E+13 6.570E+07 8.570E+07 1.849E+13 3.120E+15 3.989E+12
U-238 /FOO 1.348E+04 2.277E+05    0.        0.     5.196E+04    0.     1.633E+04
U-238 /DGM 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03
U-238 /WWT 1.835E+08 3.087E+09 7.739E+05 7.739E+05 7.050E+08 9.325E+06 2.221E+08
U-238 /SWT 1.868E+08 3.144E+09 7.739E+05 7.739E+05 7.179E+08 9.325E+06 2.262E+08
U-238 /AIR 4.789E+12 8.109E+13 1.454E+10 1.454E+10 1.850E+13 3.120E+15 4.003E+12
NP-237     3.240E-07 4.670E-04 3.000E+02 2.500E+03
NP-237/ACC 5.202E+14 1.200E+16 1.120E+15 1.340E+11 3.840E+15 3.602E+14 3.740E+11
NP-237/CON 5.209E+14 1.202E+16 1.122E+15 8.400E+08 3.847E+15 3.600E+14 1.550E+12
NP-237/AGR 5.238E+14 1.209E+16 1.128E+15 8.400E+08 3.868E+15 3.600E+14 5.652E+12
NP-237/FOO 1.545E+04 4.067E+05 3.533E+04    0.     1.223E+05    0.     2.357E+04
NP-237/DGM 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04
NP-237/WWT 2.312E+08 5.546E+09 4.885E+08 7.126E+06 1.674E+09 8.113E+06 3.263E+08
NP-237/SWT 2.572E+08 6.189E+09 5.443E+08 7.126E+06 1.867E+09 8.113E+06 3.635E+08
NP-237/AIR 5.239E+14 1.209E+16 1.128E+15 1.340E+11 3.868E+15 3.602E+14 5.785E+12
PU-238     8.020E-03 4.670E-04 8.400E+02 7.200E+03
PU-238/ACC 2.000E+14 4.080E+15 2.800E+15 1.924E+10 8.801E+14 4.080E+15 3.313E+11
PU-238/CON 2.003E+14 4.091E+15 2.802E+15 8.870E+07 8.812E+14 4.080E+15 1.514E+12
PU-238/AGR 2.012E+14 4.126E+15 2.807E+15 8.870E+07 8.850E+14 4.080E+15 5.277E+12
PU-238/FOO 1.137E+03 4.522E+04 6.371E+03    0.     4.868E+03    0.     4.855E+03
PU-238/DGM 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01
PU-238/WWT 7.019E+07 2.741E+09 3.931E+08 1.025E+06 2.972E+09 1.221E+07 2.940E+08
PU-238/SWT 7.485E+07 2.926E+09 4.192E+08 1.025E+06 3.171E+09 1.221E+07 3.139E+08
PU-238/AIR 2.012E+14 4.126E+15 2.807E+15 1.924E+10 8.850E+14 4.080E+15 5.297E+12
PU-239     2.840E-05 4.670E-04 8.400E+02 7.200E+03
PU-239/ACC 2.240E+14 4.800E+15 3.120E+15 7.400E+09 9.601E+14 3.840E+15 3.034E+11
PU-239/CON 2.243E+14 4.813E+15 3.122E+15 5.170E+07 9.613E+14 3.840E+15 1.392E+12
PU-239/AGR 2.253E+14 4.854E+15 3.127E+15 5.170E+07 9.655E+14 3.840E+15 4.826E+12
PU-239/FOO 1.270E+03 5.234E+04 7.049E+03    0.     5.393E+03    0.     4.429E+03
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Listing of DATA Data File (Continued)

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PU-239/DGM 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01
PU-239/WWT 7.765E+07 3.172E+09 4.343E+08 3.934E+05 3.285E+08 1.092E+07 2.676E+08
PU-239/SWT 8.286E+07 3.386E+09 4.632E+08 3.934E+05 3.506E+08 1.092E+07 2.858E+08
PU-239/AIR 2.253E+14 4.854E+15 3.127E+15 7.400E+09 9.656E+14 3.840E+15 4.833E+12
PU-241     .5.250E-02 4.670E-04 8.400E+02 7.200E+03
PU-241/ACC 3.040E+12 7.440E+13 4.560E+13 4.780E+07 1.440E+13 6.800E+12 5.568E+09
PU-241/CON 3.046E+12 7.467E+13 4.561E+13 4.780E+07 1.443E+13 6.300E+12 2.861E+10
PU-241/AGR 3.063E+12 7.552E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-241/FOO 2.208E+01 1.097E+03 5.613E+01    0.     1.017E+02    0.     9.310E+01
PU-241/DGM 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01
PU-241/WWT 1.341E+06 6.642E+07 3.512E+06 1.310E-01 6.179E+06 1.864E+04 5.618E+06
PU-241/SWT 1.431E+06 7.091E+07 3.742E+06 1.310E-01 6.596E+06 1.864E+04 5.999E+06
PU-241/AIR 3.063E+12 7.553E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-242     2.480E-06 4.670E-04 8.400E+02 7.200E+03
PU-242/ACC 2.160E+14 4.480E+15 3.040E+15 1.441E+10 9.601E+14 3.680E+15 2.944E+11
PU-242/CON 2.163E+14 4.492E+15 3.042E+15 5.930E+07 9.613E+14 3.680E+15 1.355E+12
PU-242/AGR 2.173E+14 4.530E+15 3.047E+15 5.930E+07 9.653E+14 3.680E+15 4.722E+12
PU-242/FOO 1.224E+03 4.848E+04 6.783E+03    0.     5.194E+03    0.     4.343E+03
PU-242/DGM    0.        0.        0.        0.        0.        0.        0.
PU-242/WWT 7.520E+07 2.938E+09 4.184E+08 7.674E+05 3.168E+08 1.085E+07 2.628E+08
PU-242/SWT 8.021E+07 3.137E+09 4.462E+08 7.674E+05 3.381E+08 1.085E+07 2.806E+08
PU-242/AIR 2.173E+14 4.530E+15 3.047E+15 1.441E+10 9.654E+14 3.680E+15 4.736E+12
AM-241     1.510E-03 4.110E-03 3.000E+02 2.500E+03
AM-241/ACC 5.041E+14 7.120E+15 6.640E+15 7.869E+10 3.840E+15 4.241E+14 3.587E+11
AM-241/CON 5.049E+14 7.134E+15 6.645E+15 3.800E+08 3.847E+15 4.240E+14 1.508E+12
AM-241/AGR 5.077E+14 7.176E+15 6.660E+15 3.800E+08 3.868E+15 4.240E+14 5.355E+12
AM-241/FOO 3.599E+04 5.448E+05 1.916E+05    0.     2.707E+05    0.     4.936E+04
AM-241/DGM 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04
AM-241/WWT 2.247E+08 3.340E+09 1.189E+09 4.192E+06 1.663E+09 5.354E+06 3.047E+08
AM-241/SWT 3.721E+08 5.572E+09 1.974E+09 4.192E+06 2.772E+09 5.354E+06 5.069E+08
AM-241/AIR 5.078E+14 7.176E+15 6.660E+15 7.869E+10 3.868E+15 4.241E+14 5.434E+12
AM-243     8.720E-05 4.110E-03 3.000E+02 2.500E+03
AM-243/ACC 4.961E+14 7.040E+15 6.480E+15 9.096E+10 3.760E+15 4.001E+14 3.630E+11
AM-243/CON 4.969E+14 7.054E+15 6.485E+15 6.090E+08 3.767E+15 4.000E+14 1.713E+12
AM-243/AGR 4.996E+14 7.096E+15 6.499E+15 6.090E+08 3.787E+15 4.000E+14 6.223E+12
AM-243/FOO 3.525E+04 5.441E+05 1.849E+05    0.     2.654E+05    0.     5.787E+04
AM-243/DGM 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05
AM-243/WWT 2.208E+08 3.337E+09 1.148E+09 4.837E+06 1.631E+09 5.933E+06 3.572E+08
AM-243/SWT 3.653E+08 5.566E+09 1.906E+09 4.837E+06 2.718E+09 5.933E+06 5.942E+08
AM-243/AIR 4.997E+14 7.096E+15 6.499E+15 9.096E+10 3.788E+15 4.001E+14 6.313E+12
CM-243     2.170E-02 4.670E-04 3.000E+02 2.500E+03
CM-243/ACC 3.843E+14 6.161E+15 5.601E+15 2.444E+11 1.760E+15 4.403E+14 5.484E+11
CM-243/CON 3.846E+14 6.171E+15 5.604E+15 2.260E+09 1.763E+15 4.400E+14 1.594E+12
CM-243/AGR 3.866E+14 6.204E+15 5.616E+15 2.260E+09 1.772E+15 4.400E+14 5.629E+12
CM-243/FOO 1.113E+04 1.897E+05 7.155E+04    0.     5.195E+04    0.     2.319E+04
CM-243/DGM 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05
CM-243/WWT 1.647E+08 2.598E+09 9.970E+08 1.296E+07 7.212E+08 1.417E+07 3.269E+08
CM-243/SWT 2.087E+08 3.347E+09 1.280E+09 1.296E+07 9.264E+08 1.417E+07 4.184E+08
CM-243/AIR 3.868E+14 6.204E+15 5.617E+15 2.444E+11 1.772E+15 4.403E+14 5.871E+12
CM-244     3.940E-02 4.670E-04 3.000E+02 2.500E+03
CM-244/ACC 2.800E+14 4.400E+15 4.160E+15 1.706E+10 1.280E+15 4.400E+14 3.051E+11
CM-244/CON 2.805E+14 4.408E+15 4.163E+15 7.230E+07 1.282E+15 4.400E+14 1.533E+12
CM-244/AGR 2.820E+14 4.433E+15 4.174E+15 7.230E+07 1.289E+15 4.400E+14 5.434E+12
CM-244/FOO 8.520E+03 1.434E+05 6.145E+04    0.     3.978E+04    0.     2.241E+04
CM-244/DGM 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01
CM-244/WWT 1.170E+08 1.954E+09 8.443E+08 9.093E+05 5.430E+08 2.115E+06 3.044E+08
CM-244/SWT 1.507E+08 2.521E+09 1.087E+09 9.093E+05 7.001E+08 2.115E+06 3.929E+08
CM-244/AIR 2.820E+14 4.433E+15 4.174E+15 1.706E+10 1.289E+15 4.400E+14 5.451E+12
REGION 1   9.180E-12 2.960E-11 1.970E-04 4.930E-05 7.700E+03 2.000E+05 4.500E+06
           2.000E+02 5.000E+03 1.000E+04 4.000E+02 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 1.010E-09 1.510E-09 1.120E-07     3
           4.000E+02 8.000E+02 1.830E-10 2.610E-12
REGION 2   2.010E-11 3.180E-11 1.160E-03 3.240E-05 7.700E+03 2.000E+05 4.500E+06
           4.200E+01 4.000E+02 8.000E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.500E-10 5.250E-10 1.120E-07     3
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
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Listing of DATA Data File (Continued)

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REGION 3   2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
           1.400E+02 2.900E+03 5.800E+03 4.000E+02 1.250E+04 2.500E+04
           1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07     4
           1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4   2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
           1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
           1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07     2
           8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5   2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
           3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     2
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6   2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
           9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     4
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
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Listing of DATAD Data File

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 36   231.000 .120 .060 .030 .060 .120 .060
P-IXRESIN 1.100E-01 3.463E+04
        1 3.360E-02 1.840E-03 9.730E-05 7.300E-04 2.790E-06 2.170E-03
        1 8.150E-04 8.840E-08 1.630E-04 8.230E-07 2.440E-06 8.230E-07
        1 1.860E-02 4.710E-08 3.710E-07 9.060E-12 2.450E-05 1.820E-05
        1 5.630E-04 3.990E-08 4.134E-05 1.260E-06 8.520E-09 1.060E-05
P-CONCLIQ 1.100E-01 2.435E+05
        2 1.090E-01 2.390E-03 1.270E-04 7.080E-03 2.710E-05 2.110E-02
        2 7.920E-03 8.580E-07 2.120E-04 1.070E-06 3.160E-06 1.070E-06
        2 2.430E-02 6.150E-08 4.840E-07 1.180E-11 4.830E-05 3.310E-05
        2 1.020E-03 7.250E-08 7.102E-05 2.020E-06 1.010E-08 1.470E-05
P-FSLUDGE 1.100E-01 4.279E+03
        3 1.060E+00 1.790E-03 9.540E-05 9.670E-02 3.710E-04 2.880E-01
        3 1.080E-01 1.170E-05 1.590E-04 8.030E-07 2.370E-06 8.030E-07
        3 1.820E-02 1.460E-07 1.150E-06 2.810E-11 4.490E-05 1.550E-04
        3 4.790E-03 3.390E-07 4.551E-04 1.780E-05 2.660E-07 1.360E-04
P-FCARTRG 1.100E-01 2.177E+04
        4 1.860E+00 7.970E-04 4.250E-05 1.730E-01 6.600E-04 5.140E-01
        4 1.930E-01 2.090E-05 7.070E-05 3.580E-07 1.060E-06 3.580E-07
        4 8.120E-03 3.640E-07 2.870E-06 7.020E-11 2.370E-04 3.800E-04
        4 1.180E-02 8.340E-07 6.394E-04 1.100E-05 1.660E-07 8.440E-05
B-IXRESIN 1.200E-01 7.623E+04
        5 4.630E+00 1.340E-02 1.190E-03 2.990E-01 9.800E-04 7.700E-01
        5 2.040E-02 3.090E-05 3.080E-03 7.650E-05 2.040E-04 7.650E-05
        5 1.740E+00 5.330E-08 4.200E-07 1.020E-11 7.880E-05 5.340E-05
        5 1.850E-03 1.170E-07 9.768E-05 1.570E-06 2.330E-08 1.400E-05
B-CONCLIQ 1.200E-01 2.102E+05
        6 2.870E-01 4.350E-04 3.890E-05 2.500E-02 8.210E-05 6.440E-02
        6 1.710E-03 2.590E-06 9.970E-05 2.500E-06 6.650E-06 2.500E-06
        6 5.670E-02 3.440E-08 2.710E-07 6.610E-12 1.880E-04 9.430E-05
        6 3.280E-03 2.060E-07 2.513E-04 8.090E-06 2.230E-07 1.580E-04
B-FSLUDGE 1.200E-01 1.690E+05
        7 5.240E+00 8.790E-03 7.770E-04 4.540E-01 1.490E-03 1.170E+00
        7 3.080E-02 4.700E-05 2.000E-03 5.000E-05 1.330E-04 5.000E-05
        7 1.130E+00 3.320E-07 2.610E-06 6.380E-11 4.400E-04 2.360E-04
        7 8.200E-03 5.180E-07 4.848E-04 1.050E-05 2.560E-07 1.720E-04
P-COTRASH 2.100E-01 4.244E+05
        8 2.280E-02 2.110E-04 1.120E-05 1.860E-03 7.110E-06 5.520E-03
        8 2.070E-03 2.250E-07 1.870E-05 9.420E-08 2.780E-07 9.420E-08
        8 2.140E-03 7.890E-09 6.220E-08 1.520E-12 5.640E-06 5.530E-06
        8 1.710E-04 1.210E-08 1.085E-05 2.670E-07 2.350E-09 2.000E-06
P-NCTRASH 2.100E-01 2.178E+05
        9 5.250E-01 4.840E-03 2.570E-04 4.270E-02 1.640E-04 1.270E-01
        9 4.780E-02 5.180E-06 4.300E-04 2.170E-06 6.410E-06 2.170E-06
        9 4.920E-02 1.820E-07 1.430E-06 3.490E-11 1.300E-04 1.270E-04
        9 3.930E-03 2.790E-07 2.498E-04 6.140E-06 5.410E-08 4.600E-05
B-COTRASH 2.200E-01 2.086E+05
       10 2.350E-02 4.700E-05 4.170E-06 1.890E-03 6.210E-06 4.890E-03
       10 1.290E-04 1.960E-07 1.070E-05 2.680E-07 7.140E-07 2.680E-07
       10 6.090E-03 1.220E-09 9.600E-09 2.350E-13 2.170E-06 1.160E-06
       10 4.010E-05 2.530E-09 2.575E-06 6.510E-08 1.660E-09 1.150E-06
B-NCTRASH 2.200E-01 9.896E+04
       11 3.790E+00 7.600E-03 6.720E-04 3.050E-01 1.000E-03 7.840E-01
       11 2.080E-02 3.160E-05 1.730E-03 4.330E-05 1.150E-04 4.330E-05
       11 9.810E-01 1.970E-07 1.550E-06 3.780E-11 3.510E-04 1.860E-04
       11 6.470E-03 4.080E-07 4.152E-04 1.050E-05 2.690E-07 1.860E-04
F-COTRASH 2.110E-01 2.359E+05
       12 5.580E-06     0.        0.        0.        0.        0.
       12     0.        0.        0.        0.        0.        0.
       12     0.    1.180E-06 4.400E-06     0.        0.        0.
       12     0.        0.        0.        0.        0.        0.
F-NCTRASH 2.110E-01 4.171E+04
       13 5.330E-06     0.        0.        0.        0.        0.
       13     0.        0.        0.        0.        0.        0.
       13     0.    1.130E-06 4.200E-06     0.        0.        0.
       13     0.        0.        0.        0.        0.        0.
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Listing of DATAD Data File (Continued)

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      --      ..          ..          ..          ..          ..          ..
I-COTRASH 2.030E-01 1.407E+05
       14 1.130E-01 5.950E-02 5.250E-03     0.          0.      4.410E-03
       14     0.        0.    1.190E-03 3.390E-09       0.          0.
       14 3.780E-03     0.        0.        0.          0.          0.
      .14     0.        0.    4.760E-06     0.          0.          0.
I+COTRASH 2.030E-01 1.407E+05
       15 1.130E-01 5.950E-02 5.250E-03     0.          0.      4.410E-03
       15     0.        0.    1.190E-03 3.390E-09       0.          0.
       15 3.780E-03     0.        0.        0.          0.          0.
       15     0.        0.    4.760E-06     0.          0.          0.
N-SSTRASH 2.060E-01 1.796E+05
       16 1.120E-05     0.        0.        0.          0.          0.
       16     0.        0.        0.        0.          0.          0.
       16     0.    2.360E-06 8.800E-06     0.          0.          0.
       16     0.        0.        0.        0.          0.          0.
N+SSTRASH 2.060E-01 1.796E+05
       17 1.120E-05     0.        0.        0.          0.          0.
       17     0.        0.        0.        0.          0.          0.
       17     0.    2.360E-06 8.800E-06     0.          0.          0.
       17     0.        0.        0.        0.          0.          0.
N-LOTRASH 2.070E-01 5.064E+04
       18 3.530E-02 1.860E-02 1.640E-03     0.          0.      1.380E-03
       18     0.        0.    3.710E-04 1.060E-09       0.          0.
       18 1.180E-03     0.        0.        0.          0.          0.
       18     0.        0.    1.490E-06     0.          0.          0.
N+LOTRASH 2.070E-01 5.064E+04
       19 3.530E-02 1.860E-02 1.640E-03     0.          0.      1.380E-03
       19     0.        0.    3.710E-04 1.060E-09       0.          0.
       19 1.180E-03     0.        0.        0.          0.          0.
       19     0.        0.    1.490E-06     0.          0.          0.
F-PROCESS 3.110E-01 7.816E+04
       20 1.080E-04     0.        0.        0.          0.          0.
       20     0.        0.        0.        0.          0.          0.
       20     0.    2.300E-05 8.540E-05     0.          0.          0.
       20     0.        0.        0.        0.          0.          0.
J-PROCESS 3.120E-01 2.811E+04
       21 3.800E-04     0.        0.        0.          0.          0.
       21     0.        0.        0.        0.          0.          0.
       21     0.    1.650E-05 3.640E-04     0.          0.          0.
       21     0.        0.        0.        0.          0.          0.
I-LOSCNVL 3.030E-01 4.914E+04
       22 9.600E-03 3.270E-03 2.510E-04     0.          0.          0.
       22     0.        0.    3.550E-03     0.          0.          0.
       22     0.        0.        0.        0.          0.          0.
       22     0.        0.        0.        0.          0.          0.
I+LOSCNVL 3.030E-01 4.914E+04
       23 9.600E-03 3.270E-03 2.510E-04     0.          0.          0.
       23     0.        0.    3.550E-03     0.          0.          0.
       23     0.        0.        0.        0.          0.          0.
       23     0.        0.        0.        0.          0.          0.
I-ABSLIQD 3.030E-01 5.585E+03
       24 1.990E-01 9.260E-02 8.150E-03     0.          0.      1.320E-02
       24     0.        0.    3.550E-03 1.020E-08       0.          0.
       24 1.140E-02     0.        0.        0.          0.          0.
       24     0.        0.        0.        0.          0.          0.
I+ABSLIQD 3.030E-01 5.585E+03
       25 1.990E-01 9.260E-02 8.150E-03     0.          0.      1.320E-02
       25     0.        0.    3.550E-03 1.020E-08       0.          0.
       25 1.140E-02     0.        0.        0.          0.          0.
       25     0.        0.        0.        0.          0.          0.
I-BIOWAST 3.030E-01 1.571E+04
       26 2.060E-01 1.140E-01 1.010E-02     0.          0.      1.690E-03
       26     0.        0.    6.820E-03 6.510E-09       0.          0.
       26 7.260E-03     0.        0.        0.          0.          0.
       26     0.        0.        0.        0.          0.          0.
I+BIOWAST 3.030E-01 1.571E+04
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Listing of DATAD Data File (Continued)

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        27 2.060E-01 1.140E-01 1.010E-02     0.        0.     1.690E-03
        27     0.        0.    6.820E-03 6.510E-09     0.        0.
        27 7.260E-03     0.        0.        0.        0.        0.
        27     0.        0.        0.        0.        0.        0.
N-SSWASTE  3.060E-01 6.339E+04
        28 2.170E-04     0.        0.        0.        0.        0.
        28     0.        0.        0.        0.        0.        0.
        28     0.    4.600E-05 1.710E-04     0.        0.        0.
        28     0.        0.        0.        0.        0.        0.
N-LOWASTE  3.070E-01 6.027E+04
        29 2.110E-02 1.060E-02 9.350E-04     0.        0.     6.230E-04
        29     0.        0.    1.070E-03 7.760E-10     0.        0.
        29 8.620E-04     0.        0.        0.        0.        0.
        29     0.        0.        0.        0.        0.        0.
L-NFRCOMP  4.300E-01 2.887E+03
        30 4.040E+03     0.    2.590E-01 6.980E+02 1.400E+00 7.700E+02
        30 1.980E+02 8.190E-03     0.        0.        0.        0.
        30     0.        0.        0.        0.        0.        0.
        30     0.        0.        0.        0.        0.        0.
L-DECONRS  4.400E-01 3.499E+04
        31 1.560E+02 7.510E-03 6.870E-04 1.270E+01 4.490E-02 3.500E+01
        31 3.490E+00 1.420E-03 3.610E-02 1.200E-05 3.340E-05 1.200E-05
        31 2.710E-01 6.840E-05 5.400E-04 1.320E-08 1.260E+00 1.770E+00
        31 2.520E+01 3.870E-03 1.026E+00 3.590E-04 2.980E-04 2.510E-03
N-ISOPROD  4.040E-01 5.196E+03
        32 1.500E+01 2.740E-02 4.510E-05     0.        0.        0.
        32     0.        0.    5.140E+00 3.270E-04 2.720E-06 3.270E-04
        32 7.240E+00 1.020E-05 3.810E-05 5.330E-13 1.840E-04 5.550E-05
        32 4.750E-03 9.570E-08 2.151E-04 1.250E-06 1.380E-04 2.110E-07
N-HIGHACT  4.030E-01 2.608E+03
        33 2.100E+02     0.    1.320E-02 2.970E+01 6.560E-02 3.600E+01
        33 9.950E+00 4.470E-04     0.        0.        0.        0.
        33.    0.        0.        0.        0.        0.        0.
        33     0.        0.        0.        0.        0.        0.
N-TRITIUM  4.050E-01 3.481E+03
        34 2.330E+03 1.520E+03     0.        0.        0.        0.
        34     0.        0.        0.        0.        0.        0.
        34     0.        0.        0.        0.        0.        0.
        34     0.        0.        0.        0.        0.        0.
N-SOURCES  4.030E-01 1.865E+02
        35 5.760E+03 1.360E+03 3.190E-03     0.        0.     3.440E+01
        35 9.860E+00     0.    2.350E+01     0.        0.        0.
        35 2.930E+03     0.        0.        0.        0.        0.
        35     0.        0.    1.580E+01     0.        0.        0.
N-TARGETS  4.030E-01 1.340E+03
        36 8.040E+01 5.240E+01     0.        0.        0.        0.
        36     0.        0.        0.        0.        0.        0.
        36     0.        0.        0.        0.        0.        0.
        36     0.        0.        0.        0.        0.        0.
H-3        5.630E-02 1.150E+00 1.000E+00 1.000E+00
H-3   /ACC 1.252E+09 5.190E+07 1.252E+09 1.252E+09 1.252E+09 1.252E+09 5.190E+07
H-3   /CON 1.172E+10 5.190E+07 1.172E+10 1.172E+10 1.172E+10 1.172E+10 1.052E+10
H-3   /AGR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
H-3   /FOO 5.995E+04     0.    5.995E+04 5.995E+04 5.995E+04 5.995E+04 5.995E+04
H-3   /DGM     0.        0.        0.        0.        0.        0.        0.
H-3   /WWT 2.367E+06 1.422E-01 2.367E+06 2.367E+06 2.367E+06 2.367E+06 2.367E+06
H-3   /SWT 2.368E+06 1.422E-01 2.368E+06 2.368E+06 2.368E+06 2.368E+06 2.368E+06
H-3   /AIR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
C-14       1.210E-04 5.760E-03 1.000E+01 1.000E+01
C-14  /ACC 3.166E+09 1.405E+10 3.166E+09 3.166E+09 3.166E+09 3.166E+09 2.526E+09
C-14  /CON 6.678E+10 3.321E+11 6.678E+10 6.678E+10 6.678E+10 6.678E+10 6.614E+10
C-14  /AGR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
C-14  /FOO 3.721E+05 1.861E+06 3.721E+05 3.721E+05 3.721E+05 3.721E+05 3.721E+05
C-14  /DGM     0.        0.        0.        0.        0.        0.        0.
C-14  /WWT 1.441E+07 7.205E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07
C-14  /SWT 3.761E+07 1.880E+08 3.761E+07 3.761E+07 3.761E+07 3.761E+07 3.761E+07
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Listing of DATAD Data File (Continued)

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C-14   /AIR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
FE-55       2.670E-01 1.480E-02 6.300E+02 5.400E+03
FE-55  /ACC 1.805E+10 1.895E+10 2.413E+10 1.613E+10 1.613E+10 2.081E+11 1.925E+10
FE-55  /CON 9.283E+09 4.416E+10 3.941E+10 5.080E+07 5.080E+07 2.095E+11 2.116E+10
FE-55  /AGR 3.219E+10 1.903E+11 1.376E+11 5.080E+07 5.080E+07 2.644E+11 7.752E+10
FE-55  /FOO 3.482E+01 2.161E+02 1.493E+02     0.        0.    8.331E+01 8.566E+01
FE-55  /DGM     0.        0.        0.        0.        0.        0.        0.
FE-55  /WWT 2.727E+06 1.244E+07 8.863E+06 8.609E+05 8.609E+05 5.326E+06 5.452E+06
FE-55  /SWT 4.450E+06 2.314E+07 1.625E+07 8.609E+05 8.609E+05 9.449E+06 9.692E+06
FE-55  /AIR 4.827E+10 2.064E+11 1.537E+11 1.613E+10 1.613E+10 2.804E+11 9.360E+10
NI-59       8.660E-06 1.480E-02 4.200E+02 3.600E+03
NI-59  /ACC 3.698E+10 9.378E+10 5.058E+10 2.578E+10 2.578E+10 5.778E+10 2.850E+10
NI-59  /CON 3.872E+10 2.325E+11 8.130E+10 5.980E+07 5.980E+07 3.206E+10 1.441E+10
NI-59  /AGR 1.247E+11 7.476E+11 2.581E+11 5.980E+07 5.980E+07 3.206E+10 5.082E+10
NI-59  /FOO 3.693E+03 2.211E+04 7.590E+03     0.        0.        0.    1.563E+03
NI-59  /DGM 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03
NI-59  /WWT 8.537E+06 4.425E+07 1.609E+07 1.377E+06 1.377E+06 1.377E+06 4.405E+06
NI-59  /SWT 9.825E+06 5.196E+07 1.874E+07 1.377E+06 1.377E+06 1.377E+06 4.953E+06
NI-59  /AIR 1.505E+11 7.733E+11 2.838E+11 2.578E+10 2.578E+10 5.778E+10 7.654E+10
CO-60       1.320E-01 1.480E-02 4.200E+02 3.600E+03
CO-60  /ACC 2.358E+12 2.336E+12 2.353E+12 2.336E+12 2.336E+12 2.634E+13 2.504E+12
CO-60  /CON 1.237E+11 2.280E+10 7.599E+10 2.280E+10 2.280E+10 2.402E+13 9.593E+11
CO-60  /AGR 3.695E+11 2.280E+10 1.874E+11 2.280E+10 2.280E+10 2.402E+13 2.953E+12
CO-60  /FOO 5.274E+03     0.    2.391E+03     0.        0.        0.    4.492E+04
CO-60  /DGM 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07
CO-60  /WWT 1.432E+08 1.239E+08 1.326E+08 1.238E+08 1.238E+08 1.239E+08 2.893E+08
CO-60  /SWT 1.458E+08 1.238E+08 1.338E+08 1.238E+08 1.238E+08 1.239E+08 3.112E+08
CO-60  /AIR 2.683E+12 2.336E+12 2.500E+12 2.336E+12 2.336E+12 2.634E+13 5.266E+12
NI-63       7.530E-03 1.480E-02 4.200E+02 3.600E+03
NI-63  /ACC 3.056E+10 9.602E+11 6.576E+10 1.560E+08 1.560E+08 8.816E+10 7.436E+09
NI-63  /CON 1.040E+11 3.150E+12 2.176E+11 1.560E+08 1.560E+08 8.816E+10 3.911E+10
NI-63  /AGR 3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NI-63  /FOO 9.878E+03 2.945E+05 2.041E+04     0.        0.        0.    4.259E+03
NI-63  /DGM     0.        0.        0.        0.        0.        0.        0.
NI-63  /WWT 1.915E+07 5.711E+08 3.958E+07 4.276E-01 4.276E-01 2.416E+02 8.256E+06
NI-63  /SWT 2.260E+07 6.738E+08 4.670E+07 4.276E-01 4.276E-01 2.416E+02 9.743E+06
NI-63  /AIR 3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NB-94       3.470E-05 1.110E-02 1.000E+03 1.000E+04
NB-94  /ACC 6.102E+11 6.114E+11 6.108E+11 6.095E+11 6.107E+11 1.330E+12 6.839E+11
NB-94  /CON 1.389E+10 1.515E+10 1.454E+10 1.320E+10 1.446E+10 7.332E+11 4.432E+11
NB-94  /AGR 1.399E+10 1.548E+10 1.472E+10 1.320E+10 1.464E+10 7.332E+11 1.557E+12
NB-94  /FOO 2.116E+00 7.078E+00 3.937E+00     0.    3.892E+00     0.    2.390E+04
NB-94  /DGM 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06
NB-94  /WWT 3.193E+07 3.196E+07 3.194E+07 3.192E+07 3.194E+07 3.192E+07 1.466E+08
NB-94  /SWT 3.232E+07 3.324E+07 3.266E+07 3.192E+07 3.265E+07 3.192E+07 4.496E+09
NB-94  /AIR 6.103E+11 6.118E+11 6.111E+11 6.095E+11 6.110E+11 1.330E+12 2.153E+12
SR-90       2.470E-02 9.860E-03 9.000E+00 7.300E+01
SR-90  /ACC 2.417E+13 9.617E+13 1.668E+11 1.668E+11 1.668E+11 1.980E+11 1.892E+11
SR-90  /CON 6.394E+13 2.588E+14 1.760E+09 1.760E+09 1.760E+09 3.296E+10 4.727E+12
SR-90  /AGR 1.891E+14 7.686E+14 1.760E+09 1.760E+09 1.760E+09 3.296E+10 1.946E+13
SR-90  /FOO 6.407E+07 2.611E+08     0.        0.        0.        0.    7.543E+06
SR-90  /DGM 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04
SR-90  /WWT 9.564E+09 3.895E+10 8.835E+06 8.835E+06 8.835E+06 8.835E+06 1.134E+09
SR-90  /SWT 1.014E+10 4.128E+10 8.835E+06 8.835E+06 8.835E+06 8.835E+06 1.201E+09
SR-90  /AIR 1.892E+14 7.688E+14 1.668E+11 1.668E+11 1.668E+11 1.980E+11 1.962E+13
TC-99       3.270E-06 1.150E-01 2.000E+00 5.000E+00
TC-99  /ACC 1.176E+09 9.680E+08 2.280E+09 7.600E+08 1.996E+10 7.400E+09 7.880E+09
TC-99  /CON 2.960E+09 5.411E+09 8.890E+09 7.600E+08 1.031E+11 7.962E+09 2.240E+11
TC-99  /AGR 8.548E+09 1.933E+10 2.960E+10 7.600E+08 3.636E+11 9.720E+09 9.008E+11
TC-99  /FOO 6.566E+03 1.635E+04 2.433E+04     0.    3.061E+05 2.067E+03 7.953E+05
TC-99  /DGM     0.        0.        0.        0.        0.        0.        0.
TC-99  /WWT 4.186E+05 1.042E+06 1.551E+06 2.083E+00 1.951E+07 1.318E+05 5.069E+07
TC-99  /SWT 4.240E+05 1.056E+06 1.571E+06 2.083E+00 1.976E+07 1.335E+05 5.135E+07
TC-99  /AIR 8.548E+09 1.933E+10 2.960E+10 7.600E+08 3.636E+11 9.721E+09 9.008E+11
I-129       4.080E-08 1.150E-01 2.000E+00 5.000E+00
I-129  /ACC 9.139E+11 8.515E+11 8.515E+11 5.128E+11 8.515E+11 8.572E+11 8.521E+11
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Listing of DATAD Data File (Continued)

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I-129 /CON 2.068E+12 7.124E+11 6.123E+11 1.624E+15 1.315E+12 6.366E+09 9.787E+10
I-129 /AGR 8.346E+12 2.942E+12 2.528E+12 6.553E+15 5.433E+12 6.366E+09 4.006E+11
I-129 /FOO 6.019E+04 2.137E+04 1.836E+04 4.725E+07 3.947E+04     0.    2.901E+03
I-129 /DGM 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04
I-129 /WWT 4.289E+07 1.758E+07 1.562E+07 3.081E+10 2.938E+07 3.644E+06 5.536E+06
I-129 /SWT 4.389E+07 1.793E+07 1.592E+07 3.160E+10 3.004E+07 3.644E+06 5.584E+06
I-129 /AIR 9.197E+12 3.792E+12 3.379E+12 6.554E+15 6.284E+12 8.572E+11 1.251E+12
CS-135     2.310E-07 1.620E-04 8.500E+01 7.200E+02
CS-135/ACC 2.371E+10 9.651E+10 8.851E+10 5.080E+08 3.331E+10 1.491E+10 1.004E+09
CS-135/CON 1.566E+11 4.209E+11 3.879E+11 5.080E+08 1.466E+11 4.884E+10 8.007E+09
CS-135/AGR 5.729E+11 1.437E+12 1.326E+12 5.080E+08 5.014E+11 1.551E+11 2.994E+10
CS-135/FOO 8.836E+03 2.157E+04 1.991E+04     0.    7.531E+03 2.256E+03 4.656E+02
CS-135/DGM     0.        0.        0.        0.        0.        0.        0.
CS-135/WWT 3.318E+07 8.098E+07 7.475E+07 1.392E+00 2.829E+07 8.472E+06 1.748E+06
CS-135/SWT 1.442E+08 3.520E+08 3.250E+08 1.392E+00 1.229E+08 3.683E+07 7.600E+06
CS-135/AIR 5.729E+11 1.437E+12 1.326E+12 5.080E+08 5.014E+11 1.551E+11 2.994E+10
CS-137     2.310E-02 1.620E-04 8.500E+01 7.200E+02
CS-137/ACC 4.499E+11 5.339E+11 7.779E+11 2.419E+11 4.259E+11 3.299E+11 2.444E+11
CS-137/CON 1.397E+12 1.719E+12 2.351E+12 1.530E+09 8.010E+11 2.941E+11 3.919E+10
CS-137/AGR 5.117E+12 5.872E+12 8.030E+12 1.530E+09 2.729E+12 9.350E+11 1.491E+11
CS-137/FOO 7.896E+04 8.814E+04 1.205E+05     0.    4.092E+04 1.360E+04 2.333E+03
CS-137/DGM 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06
CS-137/WWT 3.094E+08 3.438E+08 4.655E+08 1.287E+07 1.665E+08 6.394E+07 2.163E+07
CS-137/SWT 1.302E+09 1.452E+09 1.981E+09 1.287E+07 6.808E+08 2.349E+08 5.096E+07
CS-137/AIR 5.358E+12 6.112E+12 8.270E+12 2.419E+11 2.969E+12 1.175E+12 3.895E+11
U-235      9.760E-10 1.250E-04 8.400E+02 7.200E+03
U-235 /ACC 2.062E+12 3.062E+13 2.214E+11 2.214E+11 7.262E+12 3.360E+15 5.175E+11
U-235 /CON 2.643E+12 4.361E+13 1.590E+09 1.590E+09 1.013E+13 3.360E+15 1.586E+12
U-235 /AGR 5.154E+12 8.500E+13 1.590E+09 1.590E+09 1.979E+13 3.360E+15 5.621E+12
U-235 /FOO 1.443E+04 2.378E+05     0.        0.    5.552E+04     0.    2.319E+04
U-235 /DGM 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05
U-235 /WWT 2.073E+08 3.235E+09 1.177E+07 1.177E+07 7.643E+08 2.098E+07 3.261E+08
U-235 /SWT 2.109E+08 3.294E+09 1.177E+07 1.177E+07 7.781E+08 2.098E+07 3.318E+08
U-235 /AIR 5.374E+12 8.522E+13 2.214E+11 2.214E+11 2.001E+13 3.360E+15 5.841E+12
U-238      1.540E-10 1.250E-04 8.400E+02 7.200E+03
U-238 /ACC 1.695E+12 2.882E+13 1.454E+10 1.454E+10 6.575E+12 3.120E+15 2.546E+11
U-238 /CON 2.429E+12 4.145E+13 8.570E+07 8.570E+07 9.447E+12 3.120E+15 1.147E+12
U-238 /AGR 4.774E+12 8.108E+13 8.570E+07 8.570E+07 1.849E+13 3.120E+15 3.989E+12
U-238 /FOO 1.348E+04 2.277E+05     0.        0.    5.196E+04     0.    1.633E+04
U-238 /DGM 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03
U-238 /WWT 1.835E+08 3.087E+09 7.739E+05 7.739E+05 7.050E+08 9.325E+06 2.221E+08
U-238 /SWT 1.868E+08 3.144E+09 7.739E+05 7.739E+05 7.179E+08 9.325E+06 2.262E+08
U-238 /AIR 4.789E+12 8.109E+13 1.454E+10 1.454E+10 1.850E+13 3.120E+15 4.003E+12
NP-237     3.240E-07 4.670E-04 3.000E+02 2.500E+03
NP-237/ACC 5.202E+14 1.200E+16 1.120E+15 1.340E+11 3.840E+15 3.602E+14 3.740E+11
NP-237/CON 5.209E+14 1.202E+16 1.122E+15 8.400E+08 3.847E+15 3.600E+14 1.550E+12
NP-237/AGR 5.238E+14 1.209E+16 1.128E+15 8.400E+08 3.868E+15 3.600E+14 5.652E+12
NP-237/FOO 1.645E+04 4.067E+05 3.533E+04     0.    1.223E+05     0.    2.357E+04
NP-237/DGM 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04
NP-237/WWT 2.312E+08 5.546E+09 4.885E+08 7.126E+06 1.674E+09 8.113E+06 3.263E+08
NP-237/SWT 2.572E+08 6.189E+09 5.443E+08 7.126E+06 1.867E+09 8.113E+06 3.635E+08
NP-237/AIR 5.239E+14 1.209E+16 1.128E+15 1.340E+11 3.868E+15 3.602E+14 5.785E+12
PU-238     8.020E-03 4.670E-04 8.400E+02 7.200E+03
PU-238/ACC 2.000E+14 4.080E+15 2.800E+15 1.924E+10 8.801E+14 4.080E+15 3.313E+11
PU-238/CON 2.003E+14 4.091E+15 2.802E+15 8.870E+07 8.812E+14 4.080E+15 1.514E+12
PU-238/AGR 2.012E+14 4.126E+15 2.807E+15 8.870E+07 8.850E+14 4.080E+15 5.277E+12
PU-238/FOO 1.137E+03 4.522E+04 6.371E+03     0.    4.868E+03     0.    4.855E+03
PU-238/DGM 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01
PU-238/WWT 7.019E+07 2.741E+09 3.931E+08 1.025E+06 2.972E+08 1.221E+07 2.940E+08
PU-238/SWT 7.485E+07 2.926E+09 4.192E+08 1.025E+06 3.171E+08 1.221E+07 3.139E+08
PU-238/AIR 2.[illegible]12E+14 4.126E+15 2.807E+15 1.924E+10 8.850E+14 4.080E+15 5.297E+12
PU-239     2.840E-05 4.670E-04 8.400E+02 7.200E+03
PU-239/ACC 2.240E+14 4.800E+15 3.120E+15 7.400E+09 9.601E+14 3.840E+15 3.034E+11
PU-239/CON 2.243E+14 4.813E+15 3.122E+15 5.170E+07 9.613E+14 3.840E+15 1.392E+12
PU-239/AGR 2.253E+14 4.854E+15 3.127E+15 5.170E+07 9.655E+14 3.840E+15 4.826E+12
PU-239/FOO 1.270E+03 5.234E+04 7.049E+03     0.    5.393E+03     0.    4.429E+03
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Listing of DATAD Data File (Continued)

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PU-239/DGM 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01
PU-239/WWT 7.765E+07 3.172E+09 4.343E+08 3.934E+05 3.285E+08 1.092E+07 2.676E+08
PU-239/SWT 8.286E+07 3.386E+09 4.632E+08 3.934E+05 3.506E+08 1.092E+07 2.858E+08
PU-239/AIR 2.253E+14 4.854E+15 3.127E+15 7.400E+09 9.656E+14 3.840E+15 4.833E+12
PU-241     5.250E-02 4.670E-04 8.400E+02 7.200E+03
PU-241/ACC 3.040E+12 7.440E+13 4.560E+13 4.780E+07 1.440E+13 6.800E+12 5.568E+09
PU-241/CON 3.046E+12 7.467E+13 4.561E+13 4.780E+07 1.443E+13 6.800E+12 2.361E+10
PU-241/AGR 3.063E+12 7.552E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-241/FOO 2.208E+01 1.097E+03 5.613E+01    0.     1.017E+02    0.     9.310E+01
PU-241/DGM 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01
PU-241/WWT 1.341E+06 6.642E+07 3.512E+06 1.310E-01 6.179E+06 1.864E+04 5.618E+06
PU-241/SWT 1.431E+06 7.091E+07 3.742E+06 1.310E-01 6.596E+06 1.864E+04 5.999E+06
PU-241/AIR 3.063E+12 7.553E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-242     2.480E-06 4.670E-04 8.400E+02 7.200E+03
PU-242/ACC 2.160E+14 4.480E+15 3.040E+15 1.441E+10 9.601E+14 3.680E+15 2.944E+11
PU-242/CON 2.163E+14 4.492E+15 3.042E+15 6.930E+07 9.613E+14 3.690E+15 1.355E+12
PU-242/AGR 2.173E+14 4.530E+15 3.047E+15 6.930E+07 9.653E+14 3.680E+15 4.722E+12
PU-242/FOO 1.224E+03 4.848E+04 6.783E+03    0.     5.194E+03    0.     4.343E+03
PU-242/DGM    0.        0.        0.        0.        0.        0.        0.
PU-242/WWT 7.520E+07 2.938E+09 4.194E+08 7.674E+05 3.168E+08 1.085E+07 2.628E+08
PU-242/SWT 8.021E+07 3.137E+09 4.462E+08 7.674E+05 3.391E+08 1.085E+07 2.806E+08
PU-242/AIR 2.173E+14 4.530E+15 3.047E+15 1.441E+10 9.654E+14 3.680E+15 4.736E+12
AM-241     1.510E-03 4.110E-03 3.000E+02 2.500E+03
AM-241/ACC 5.041E+14 7.120E+15 6.640E+15 7.869E+10 3.840E+15 4.241E+14 3.587E+11
AM-241/CON 5.049E+14 7.134E+15 6.645E+15 3.800E+08 3.847E+15 4.240E+14 1.508E+12
AM-241/AGR 5.077E+14 7.176E+15 6.660E+15 3.800E+08 3.868E+15 4.240E+14 5.355E+12
AM-241/FOO 3.599E+04 5.448E+05 1.916E+05    0.     2.707E+05    0.     4.936E+04
AM-241/DGM 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04
AM-241/WWT 2.247E+08 3.340E+09 1.189E+09 4.192E+06 1.663E+09 5.354E+06 3.047E+08
AM-241/SWT 3.721E+08 5.572E+09 1.974E+09 4.192E+06 2.772E+09 5.354E+06 5.069E+08
AM-241/AIR 5.078E+14 7.176E+15 6.660E+15 7.869E+10 3.868E+15 4.241E+14 5.434E+12
AM-243     8.720E-05 4.110E-03 3.000E+02 2.500E+03
AM-243/ACC 4.961E+14 7.040E+15 6.480E+15 9.096E+10 3.760E+15 4.001E+14 3.630E+11
AM-243/CON 4.969E+14 7.054E+15 6.485E+15 6.090E+08 3.767E+15 4.000E+14 1.713E+12
AM-243/AGR 4.996E+14 7.096E+15 6.499E+15 6.090E+08 3.787E+15 4.000E+14 6.223E+12
AM-243/FOO 3.525E+04 5.441E+05 1.849E+05    0.     2.654E+05    0.     5.787E+04
AM-243/DGM 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05
AM-243/WWT 2.208E+08 3.337E+09 1.148E+09 4.837E+06 1.631E+09 5.933E+06 3.572E+08
AM-243/SWT 3.653E+08 5.566E+09 1.906E+09 4.837E+06 2.718E+09 5.933E+06 5.942E+08
AM-243/AIR 4.997E+14 7.096E+15 6.499E+15 9.096E+10 3.788E+15 4.001E+14 6.313E+12
CM-243     2.170E-02 4.670E-04 3.000E+02 2.500E+03
CM-243/ACC 3.843E+14 6.161E+15 5.601E+15 2.444E+11 1.760E+15 4.403E+14 5.484E+11
CM-243/CON 3.846E+14 6.171E+15 5.604E+15 2.260E+09 1.763E+15 4.400E+14 1.594E+12
CM-243/AGR 3.866E+14 6.204E+15 5.616E+15 2.260E+09 1.772E+15 4.400E+14 5.629E+12
CM-243/FOO 1.113E+04 1.897E+05 7.155E+04    0.     5.195E+04    0.     2.319E+04
CM-243/DGM 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05
CM-243/WWT 1.647E+08 2.598E+09 9.970E+08 1.296E+07 7.212E+08 1.417E+07 3.269E+08
CM-243/SWT 2.087E+08 3.347E+09 1.280E+09 1.296E+07 9.264E+08 1.417E+07 4.184E+08
CM-243/AIR 3.868E+14 6.204E+15 5.617E+15 2.444E+11 1.772E+15 4.403E+14 5.871E+12
CM-244     3.940E-02 4.670E-04 3.000E+02 2.500E+03
CM-244/ACC 2.800E+14 4.400E+15 4.160E+15 1.706E+10 1.280E+15 4.400E+14 3.051E+11
CM-244/CON 2.805E+14 4.408E+15 4.163E+15 7.230E+07 1.282E+15 4.400E+14 1.533E+12
CM-244/AGR 2.820E+14 4.433E+15 4.174E+15 7.230E+07 1.289E+15 4.400E+14 5.434E+12
CM-244/FOO 8.520E+03 1.434E+05 6.145E+04    0.     3.978E+04    0.     2.241E+04
CM-244/DGM 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01
CM-244/WWT 1.170E+08 1.954E+09 8.443E+08 9.093E+05 5.430E+08 2.115E+06 3.044E+08
CM-244/SWT 1.507E+08 2.521E+09 1.087E+09 9.093E+05 7.001E+08 2.115E+06 3.929E+08
CM-244/AIR 2.820E+14 4.433E+15 4.174E+15 1.706E+10 1.289E+15 4.400E+14 5.451E+12
REGION 1   9.180E-12 2.960E-11 1.970E-04 4.930E-05 7.700E+03 2.000E+05 4.500E+06
           2.000E+02 5.000E+03 1.000E+04 4.000E+02 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 1.010E-09 1.510E-09 1.120E-07     3
           4.000E+02 8.000E+02 1.830E-10 2.610E-12
REGION 2   2.010E-11 3.180E-11 1.160E-03 3.240E-05 7.700E+03 2.000E+05 4.500E+06
           4.200E+01 4.000E+02 8.000E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.500E-10 5.250E-10 1.120E-07     3
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
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Listing of DATAD Data File (Continued)

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REGION 3   2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
           1.400E+02 2.900E+03 5.800E+03 4.000E+02 1.250E+04 2.500E+04
           1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07     4
           1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4   2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
           1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
           1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07     2
           8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5   2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
           3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     2
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6   2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
           9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     4
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
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Listing of NUCS Data File

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   36    23 1.00  .12   .06  .03   .06  .12   .06
H-3          5.630E-02 1.150E+00 1.000E+00 1.000E+00
H-3    /ACC 1.252E+09 5.190E+07 1.252E+09 1.252E+09 1.252E+09 1.252E+09 5.190E+07
H-3    /CON 1.172E+10 5.190E+07 1.172E+10 1.172E+10 1.172E+10 1.172E+10 1.052E+10
H-3    /AGR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
H-3    /FOO 5.995E+04     0.    5.995E+04 5.995E+04 5.995E+04 5.995E+04 5.995E+04
H-3    /DGM     0.        0.        0.        0.        0.        0.        0.
H-3    /WWT 2.367E+06 1.422E-01 2.367E+06 2.367E+06 2.367E+06 2.367E+06 2.367E+06
H-3    /SWT 2.368E+06 1.422E-01 2.368E+06 2.368E+06 2.368E+06 2.368E+06 2.368E+06
H-3    /AIR 4.451E+10 5.190E+07 4.451E+10 4.451E+10 4.451E+10 4.451E+10 4.331E+10
C-14         1.210E-04 5.760E-03 1.000E+01 1.000E+01
C-14   /ACC 3.166E+09 1.405E+10 3.166E+09 3.166E+09 3.166E+09 3.166E+09 2.526E+09
C-14   /CON 6.678E+10 3.321E+11 6.678E+10 6.678E+10 6.678E+10 6.678E+10 6.614E+10
C-14   /AGR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
C-14   /FOO 3.721E+05 1.861E+06 3.721E+05 3.721E+05 3.721E+05 3.721E+05 3.721E+05
C-14   /DGM     0.        0.        0.        0.        0.        0.        0.
C-14   /WWT 1.441E+07 7.205E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07 1.441E+07
C-14   /SWT 3.761E+07 1.880E+08 3.761E+07 3.761E+07 3.761E+07 3.761E+07 3.761E+07
C-14   /AIR 2.660E+11 1.328E+12 2.660E+11 2.660E+11 2.660E+11 2.660E+11 2.654E+11
FE-55        2.670E-01 1.480E-02 5.300E+02 5.400E+03
FE-55 /ACC 1.805E+10 1.985E+10 2.413E+10 1.613E+10 1.613E+10 2.081E+11 1.925E+10
FE-55 /CON 9.283E+09 4.816E+10 3.941E+10 5.080E+07 5.080E+07 2.095E+11 2.116E+10
FE-55 /AGR 3.219E+10 1.903E+11 1.376E+11 5.080E+07 5.080E+07 2.644E+11 7.752E+10
FE-55 /FOO 3.482E+01 2.161E+02 1.493E+02     0.        0.    8.331E+01 8.566E+01
FE-55 /DGM     0.        0.        0.        0.        0.        0.        0.
FE-55 /WWT 2.727E+06 1.244E+07 8.863E+06 8.609E+05 8.609E+05 5.326E+06 5.452E+06
FE-55 /SWT 4.450E+06 2.314E+07 1.625E+07 8.609E+05 8.609E+05 9.449E+06 9.692E+06
FE-55 /AIR 4.827E+10 2.064E+11 1.537E+11 1.613E+10 1.613E+10 2.804E+11 9.360E+10
NI-59        8.660E-06 1.480E-02 4.200E+02 3.600E+03
NI-59 /ACC 3.698E+10 9.378E+10 5.058E+10 2.578E+10 2.578E+10 5.778E+10 2.850E+10
NI-59 /CON 3.872E+10 2.325E+11 8.130E+10 5.980E+07 5.980E+07 3.206E+10 1.441E+10
NI-59 /AGR 1.247E+11 7.476E+11 2.581E+11 5.980E+07 5.980E+07 3.206E+10 5.082E+10
NI-59 /FOO 3.693E+03 2.211E+04 7.590E+03     0.        0.        0.    1.563E+03
NI-59 /DGM 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03 6.200E+03
NI-59 /WWT 8.537E+06 4.425E+07 1.609E+07 1.377E+06 1.377E+06 1.377E+06 4.408E+06
NI-59 /SWT 9.825E+06 5.196E+07 1.874E+07 1.377E+06 1.377E+06 1.377E+06 4.953E+06
NI-59 /AIR 1.505E+11 7.733E+11 2.838E+11 2.578E+10 2.578E+10 5.778E+10 7.654E+10
CO-60        1.320E-01 1.480E-02 4.200E+02 3.600E+03
CO-60 /ACC 2.358E+12 2.336E+12 2.353E+12 2.336E+12 2.336E+12 2.634E+13 2.504E+12
CO-60 /CON 1.237E+11 2.280E+10 7.599E+10 2.280E+10 2.280E+10 2.402E+13 8.593E+11
CO-60 /AGR 3.695E+11 2.280E+10 1.874E+11 2.280E+10 2.280E+10 2.402E+13 2.953E+12
CO-60 /FOO 5.274E+03     0.    2.391E+03     0.        0.        0.    4.492E+04
CO-60 /DGM 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07 1.540E+07
CO-60 /WWT 1.432E+08 1.238E+08 1.326E+08 1.238E+08 1.238E+08 1.239E+08 2.893E+08
CO-60 /SWT 1.458E+08 1.238E+08 1.338E+08 1.238E+08 1.238E+08 1.239E+08 3.112E+04
CO-60 /AIR 2.683E+12 2.336E+12 2.500E+12 2.336E+12 2.336E+12 2.634E+13 5.266E+12
NI-63        7.530E-03 1.480E-02 4.200E+02 3.600E+03
NI-63 /ACC 3.056E+10 9.602E+11 6.576E+10 1.560E+08 1.560E+08 8.816E+10 7.436E+09
NI-63 /CON 1.040E+11 3.150E+12 2.176E+11 1.560E+08 1.560E+08 8.816E+10 3.911E+10
NI-63 /AGR 3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NI-63 /FOO 9.878E+03 2.945E+05 2.041E+04     0.        0.        0.    4.259E+03
NI-63 /DGM     0.        0.        0.        0.        0.        0.        0.
NI-63 /WWT 1.915E+07 5.711E+08 3.958E+07 4.276E-01 4.276E-01 2.416E+02 8.258E+06
NI-63 /SWT 2.260E+07 6.738E+08 4.670E+07 4.276E-01 4.276E-01 2.416E+02 9.743E+06
NI-63 /AIR 3.341E+11 1.001E+13 6.931E+11 1.560E+08 1.560E+08 8.816E+10 1.383E+11
NB-94        3.470E-05 1.110E-02 1.000E+03 1.000E+04
NB-94 /ACC 6.102E+11 6.114E+11 6.108E+11 6.095E+11 6.107E+11 1.330E+12 6.839E+11
NB-94 /CON 1.389E+10 1.515E+10 1.454E+10 1.320E+10 1.446E+10 7.332E+11 4.432E+11
NB-94 /AGR 1.399E+10 1.548E+10 1.472E+10 1.320E+10 1.464E+10 7.332E+11 1.557E+12
NB-94 /FOO 2.116E+00 7.078E+00 3.937E+00     0.    3.892E+00     0.    2.390E+04
NB-94 /DGM 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06 9.630E+06
NB-94 /WWT 3.193E+07 3.196E+07 3.194E+07 3.192E+07 3.194E+07 3.192E+07 1.466E+08
NB-94 /SWT 3.232E+07 3.324E+07 3.266E+07 3.192E+07 3.265E+07 3.192E+07 4.496E+09
NB-94 /AIR 6.103E+11 6.118E+11 6.111E+11 6.095E+11 6.110E+11 1.330E+12 2.153E+12
SR-90        2.470E-02 9.860E-03 9.000E+00 7.300E+01
SR-90 /ACC 2.417E+13 9.617E+13 1.668E+11 1.668E+11 1.668E+11 1.980E+11 1.892E+11
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Listing of NUCS Data File (Continued)

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SR-90 /CON 6.394E+13 2.588E+14 1.760E+09 1.760E+09 1.760E+09 3.296E+10 4.727E+12
SR-90 /AGR 1.891E+14 7.686E+14 1.760E+09 1.760E+09 1.760E+09 3.296E+10 1.946E+13
SR-90 /FOO 6.407E+07 2.611E+08     0.        0.        0.        0.     7.543E+06
SR-90 /DGM 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04 3.060E+04
SR-90 /WWT 9.564E+09 3.895E+10 8.835E+06 8.835E+06 8.835E+06 8.835E+06 1.134E+09
SR-90 /SWT 1.014E+10 4.128E+10 8.835E+06 8.835E+06 8.835E+06 8.835E+06 1.201E+09
SR-90 /AIR 1.892E+14 7.688E+14 1.668E+11 1.668E+11 1.668E+11 1.980E+11 1.962E+13
TC-99      3.270E-06 1.150E-01 2.000E+00 5.000E+00
TC-99 /ACC 1.176E+09 9.680E+08 2.280E+09 7.600E+08 1.996E+10 7.400E+09 7.880E+09
TC-99 /CON 2.960E+09 5.411E+09 8.890E+09 7.600E+08 1.031E+11 7.962E+09 2.240E+11
TC-99 /AGR 8.548E+09 1.933E+10 2.960E+10 7.600E+08 3.636E+11 9.720E+09 9.008E+11
TC-99 /FOO 6.566E+03 1.635E+04 2.433E+04     0.    3.061E+05 2.067E+03 7.953E+05
TC-99 /DGM     0.        0.        0.        0.        0.        0.        0.
TC-99 /WWT 4.186E+05 1.042E+06 1.551E+06 2.083E+00 1.951E+07 1.318E+05 5.069E+07
TC-99 /SWT 4.240E+05 1.056E+06 1.571E+06 2.083E+00 1.976E+07 1.335E+05 5.135E+07
TC-99 /AIR 8.548E+09 1.933E+10 2.960E+10 7.600E+08 3.636E+11 9.721E+09 9.008E+11
I-129      4.080E-08 1.150E-01 2.000E+00 5.000E+00
I-129 /ACC 9.139E+11 8.515E+11 8.515E+11 5.128E+13 8.515E+11 8.572E+11 8.521E+11
I-129 /CON 2.068E+12 7.124E+11 6.123E+11 1.624E+15 1.315E+12 6.366E+09 9.787E+10
I-129 /AGR 8.346E+12 2.942E+12 2.528E+12 6.553E+15 5.433E+12 6.366E+09 4.006E+11
I-129 /FOO 6.019E+04 2.137E+04 1.836E+04 4.725E+07 3.947E+04     0.    2.901E+03
I-129 /DGM 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04 1.920E+04
I-129 /WWT 4.289E+07 1.758E+07 1.562E+07 3.081E+10 2.938E+07 3.644E+06 5.536E+06
I-129 /SWT 4.389E+07 1.793E+07 1.592E+07 3.160E+10 3.004E+07 3.644E+06 5.584E+06
I-129 /AIR 9.197E+12 3.792E+12 3.379E+12 6.554E+15 6.284E+12 8.572E+11 1.251E+12
CS-135     2.310E-07 1.620E-04 8.500E+01 7.200E+02
CS-135/ACC 2.371E+10 9.651E+10 8.851E+10 5.080E+08 3.331E+10 1.491E+10 1.004E+09
CS-135/CON 1.566E+11 4.209E+11 3.879E+11 5.080E+08 1.466E+11 4.884E+10 8.007E+09
CS-135/AGR 5.729E+11 1.437E+12 1.326E+12 5.080E+08 5.014E+11 1.551E+11 2.994E+10
CS-135/FOO 8.836E+03 2.157E+04 1.991E+04     0.    7.531E+03 2.256E+03 4.656E+02
CS-135/DGM     0.        0.        0.        0.        0.        0.        0.
CS-135/WWT 3.318E+07 8.098E+07 7.475E+07 1.392E+00 2.828E+07 8.472E+06 1.748E+06
CS-135/SWT 1.442E+08 3.520E+08 3.250E+08 1.392E+00 1.229E+08 3.683E+07 7.600E+06
CS-135/AIR 5.729E+11 1.437E+12 1.326E+12 5.080E+08 5.014E+11 1.551E+11 2.994E+10
CS-137     2.310E-02 1.620E-04 8.500E+01 7.200E+02
CS-137/ACC 4.499E+11 6.339E+11 7.779E+11 2.419E+11 4.259E+11 3.299E+11 2.444E+11
CS-137/CON 1.397E+12 1.719E+12 2.351E+12 1.530E+09 8.010E+11 2.941E+11 3.919E+10
CS-137/AGR 5.117E+12 5.872E+12 8.030E+12 1.530E+09 2.729E+12 9.350E+11 1.491E+11
CS-137/FOO 7.896E+04 8.814E+04 1.205E+05     0.    4.092E+04 1.360E+04 2.333E+03
CS-137/DGM 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06 3.500E+06
CS-137/WWT 3.094E+08 3.438E+08 4.655E+08 1.287E+07 1.665E+08 6.394E+07 2.163E+07
CS-137/SWT 1.302E+09 1.452E+09 1.981E+09 1.287E+07 6.808E+08 2.349E+08 5.096E+07
CS-137/AIR 5.358E+12 6.112E+12 8.270E+12 2.419E+11 2.969E+12 1.175E+12 3.895E+11
U-235      9.760E-10 1.250E-04 8.400E+02 7.200E+03
U-235 /ACC 2.062E+12 3.062E+13 2.214E+11 2.214E+11 7.262E+12 3.360E+15 5.175E+11
U-235 /CON 2.643E+12 4.361E+13 1.590E+09 1.590E+09 1.013E+13 3.360E+15 1.586E+12
U-235 /AGR 5.154E+12 8.500E+13 1.590E+09 1.590E+09 1.979E+13 3.360E+15 5.621E+12
U-235 /FOO 1.443E+04 2.378E+05     0.        0.    5.552E+04     0.    2.319E+04
U-235 /DGM 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05 1.500E+05
U-235 /WWT 2.073E+08 3.235E+09 1.177E+07 1.177E+07 7.643E+08 2.098E+07 3.261E+08
U-235 /SWT 2.109E+08 3.294E+09 1.177E+07 1.177E+07 7.781E+08 2.098E+07 3.318E+08
U-235 /AIR 5.374E+12 8.522E+13 2.214E+11 2.214E+11 2.001E+13 3.360E+15 5.841E+12
U-238      1.540E-10 1.250E-04 8.400E+02 7.200E+03
U-238 /ACC 1.695E+12 2.882E+13 1.454E+10 1.454E+10 6.575E+12 3.120E+15 2.546E+11
U-238 /CON 2.429E+12 4.145E+13 8.570E+07 8.570E+07 9.447E+12 3.120E+15 1.147E+12
U-238 /AGR 4.774E+12 8.108E+13 8.570E+07 8.570E+07 1.849E+13 3.120E+15 3.989E+12
U-238 /FOO 1.348E+04 2.277E+05     0.        0.    5.196E+04     0.    1.633E+04
U-238 /DGM 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03 5.160E+03
U-238 /WWT 1.835E+08 3.087E+09 7.739E+05 7.739E+05 7.050E+08 9.325E+06 2.221E+08
U-238 /SWT 1.868E+08 3.144E+09 7.739E+05 7.739E+05 7.179E+08 9.325E+06 2.262E+08
U-238 /AIR 4.789E+12 8.109E+13 1.454E+10 1.454E+10 1.850E+13 3.120E+15 4.003E+12
NP-237     3.240E-07 4.670E-04 3.000E+02 2.500E+03
NP-237/ACC 5.202E+14 1.200E+16 1.120E+15 1.340E+11 3.840E+15 3.602E+14 3.740E+11
NP-237/CON 5.209E+14 1.202E+16 1.122E+15 8.400E+08 3.847E+15 3.600E+14 1.550E+12
NP-237/AGR 5.238E+14 1.209E+16 1.128E+15 8.400E+08 3.868E+15 3.600E+14 5.652E+12
NP-237/FOO 1.645E+04 4.067E+05 3.533E+04     0.    1.223E+05     0.    2.357E+04
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Listing of NUCS Data File (Continued)

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NP-237/DGM 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04 6.560E+04
NP-237/WWT 2.312E+08 5.546E+09 4.885E+08 7.126E+06 1.674E+09 8.113E+06 3.263E+08
NP-237/SWT 2.572E+08 6.189E+09 5.443E+08 7.126E+06 1.867E+09 8.113E+06 3.635E+08
NP-237/AIR 5.239E+14 1.209E+16 1.128E+15 1.340E+11 3.868E+15 3.602E+14 5.785E+12
PU-238     8.020E-03 4.670E-04 8.400E+02 7.200E+03
PU-238/ACC 2.000E+14 4.080E+15 2.800E+15 1.924E+10 8.801E+14 4.080E+15 3.313E+11
PU-238/CON 2.003E+14 4.091E+15 2.802E+15 8.870E+07 8.812E+14 4.080E+15 1.514E+12
PU-238/AGR 2.012E+14 4.126E+15 2.807E+15 8.870E+07 8.850E+14 4.080E+15 5.277E+12
PU-238/FOO 1.137E+03 4.522E+04 6.371E+03    0.     4.868E+03    0.     4.855E+03
PU-238/DGM 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01 1.930E+01
PU-238/WWT 7.019E+07 2.741E+09 3.931E+08 1.025E+06 2.972E+08 1.221E+07 2.940E+08
PU-238/SWT 7.485E+07 2.926E+09 4.192E+08 1.025E+06 3.171E+08 1.221E+07 3.139E+08
PU-238/AIR 2.012E+14 4.126E+15 2.807E+15 1.924E+10 8.850E+14 4.080E+15 5.297E+12
PU-239     2.840E-05 4.670E-04 8.400E+02 7.200E+03
PU-239/ACC 2.240E+14 4.800E+15 3.120E+15 7.400E+09 9.601E+14 3.840E+15 3.034E+11
PU-239/CON 2.243E+14 4.813E+15 3.122E+15 5.170E+07 9.613E+14 3.840E+15 1.392E+12
PU-239/AGR 2.253E+14 4.854E+15 3.127E+15 5.170E+07 9.655E+14 3.840E+15 4.826E+12
PU-239/FOO 1.270E+03 5.234E+04 7.049E+03    0.     5.393E+03    0.     4.429E+03
PU-239/DGM 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01 9.390E+01
PU-239/WWT 7.765E+07 3.172E+09 4.343E+08 3.934E+05 3.285E+08 1.092E+07 2.676E+08
PU-239/SWT 8.266E+07 3.386E+09 4.632E+08 3.934E+05 3.506E+08 1.092E+07 2.858E+08
PU-239/AIR 2.253E+14 4.854E+15 3.127E+15 7.400E+09 9.656E+14 3.840E+15 4.833E+12
PU-241     5.250E-02 4.670E-04 8.400E+02 7.200E+03
PU-241/ACC 3.040E+12 7.440E+13 4.560E+13 4.780E+07 1.440E+13 6.800E+12 5.568E+09
PU-241/CON 3.046E+12 7.467E+13 4.561E+13 4.780E+07 1.443E+13 6.800E+12 2.861E+10
PU-241/AGR 3.063E+12 7.552E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-241/FOO 2.208E+01 1.097E+03 5.613E+01    0.     1.017E+02    0.     9.310E+01
PU-241/DGM 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01 3.430E-01
PU-241/WWT 1.341E+06 6.642E+07 3.512E+06 1.310E-01 6.179E+06 1.864E+04 5.618E+06
PU-241/SWT 1.431E+06 7.091E+07 3.742E+06 1.310E-01 6.596E+06 1.864E+04 5.999E+06
PU-241/AIR 3.063E+12 7.553E+13 4.566E+13 4.780E+07 1.450E+13 6.800E+12 1.008E+11
PU-242     2.480E-06 4.670E-04 8.400E+02 7.200E+03
PU-242/ACC 2.160E+14 4.480E+15 3.040E+15 1.441E+10 9.601E+14 3.680E+15 2.944E+11
PU-242/CON 2.163E+14 4.492E+15 3.042E+15 6.930E+07 9.613E+14 3.680E+15 1.355E+12
PU-242/AGR 2.173E+14 4.530E+15 3.047E+15 6.930E+07 9.653E+14 3.680E+15 4.722E+12
PU-242/FOO 1.224E+03 4.848E+04 6.783E+03    0.     5.194E+03    0.     4.343E+03
PU-242/DGM    0.        0.        0.        0.        0.        0.        0.
PU-242/WWT 7.520E+07 2.938E+09 4.184E+08 7.674E+05 3.168E+08 1.085E+07 2.628E+08
PU-242/SWT 8.021E+07 3.137E+09 4.462E+08 7.674E+05 3.381E+08 1.085E+07 2.806E+08
PU-242/AIR 2.173E+14 4.530E+15 3.047E+15 1.441E+10 9.654E+14 3.680E+15 4.736E+12
AM-241     1.510E-03 4.110E-03 3.000E+02 2.500E+03
AM-241/ACC 5.041E+14 7.120E+15 6.640E+15 7.869E+10 3.840E+15 4.241E+14 3.587E+11
AM-241/CON 5.049E+14 7.134E+15 6.645E+15 3.800E+08 3.847E+15 4.240E+14 1.508E+12
AM-241/AGR 5.077E+14 7.176E+15 6.660E+15 3.800E+08 3.868E+15 4.240E+14 5.355E+12
AM-241/FOO 3.599E+04 5.448E+05 1.916E+05    0.     2.707E+05    0.     4.936E+04
AM-241/DGM 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04 7.710E+04
AM-241/WWT 2.247E+08 3.340E+09 1.189E+09 4.192E+06 1.663E+09 5.354E+06 3.047E+08
AM-241/SWT 3.721E+08 5.572E+09 1.974E+09 4.192E+06 2.772E+09 5.354E+06 5.069E+08
AM-241/AIR 5.078E+14 7.176E+15 6.660E+15 7.869E+10 3.868E+15 4.241E+14 5.434E+12
AM-243     8.720E-05 4.110E-03 3.000E+02 2.500E+03
AM-243/ACC 4.961E+14 7.040E+15 6.480E+15 9.096E+10 3.760E+15 4.001E+14 3.630E+11
AM-243/CON 4.969E+14 7.054E+15 6.485E+15 6.090E+08 3.767E+15 4.000E+14 1.713E+12
AM-243/AGR 4.996E+14 7.096E+15 6.499E+15 6.090E+08 3.787E+15 4.000E+14 6.223E+12
AM-243/FOO 3.525E+04 5.441E+05 1.849E+05    0.     2.654E+05    0.     5.787E+04
AM-243/DGM 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05 1.860E+05
AM-243/WWT 2.208E+08 3.337E+09 1.148E+09 4.837E+06 1.631E+09 5.933E+06 3.572E+08
AM-243/SWT 3.653E+08 5.566E+09 1.906E+09 4.837E+06 2.718E+09 5.933E+06 5.942E+08
AM-243/AIR 4.997E+14 7.096E+15 6.499E+15 9.096E+10 3.788E+15 4.001E+14 6.313E+12
CM-243     2.170E-02 4.670E-04 3.000E+02 2.500E+03
CM-243/ACC 3.843E+14 6.161E+15 5.601E+15 2.444E+11 1.760E+15 4.403E+14 5.484E+11
CM-243/CON 3.846E+14 6.171E+15 5.604E+15 2.260E+09 1.763E+15 4.400E+14 1.594E+12
CM-243/AGR 3.866E+14 6.204E+15 5.616E+15 2.260E+09 1.772E+15 4.400E+14 5.629E+12
CM-243/FOO 1.113E+04 1.897E+05 7.155E+04    0.     5.195E+04    0.     2.319E+04
CM-243/DGM 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05 3.820E+05
CM-243/WWT 1.647E+08 2.598E+09 9.970E+08 1.296E+07 7.212E+08 1.417E+07 3.269E+08
CM-243/SWT 2.087E+08 3.347E+09 1.280E+09 1.296E+07 9.264E+08 1.417E+07 4.184E+08
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Listing of NUCS Data File (Continued)

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CM-243/AIR 3.868E+14 6.204E+15 5.617E+15 2.444E+11 1.772E+15 4.403E+14 5.871E+12
CM-244     3.940E-02 4.670E-04 3.000E+02 2.500E+03
CM-244/ACC 2.800E+14 4.400E+15 4.160E+15 1.706E+10 1.280E+15 4.400E+14 3.051E+11
CM-244/CON 2.805E+14 4.408E+15 4.163E+15 7.230E+07 1.282E+15 4.400E+14 1.533E+12
CM-244/AGR 2.820E+14 4.433E+15 4.174E+15 7.230E+07 1.289E+15 4.400E+14 5.434E+12
CM-244/FOO 8.520E+03 1.434E+05 6.145E+04     0.    3.978E+04     0.    2.241E+04
CM-244/DGM 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01 5.640E+01
CM-244/WWT 1.170E+08 1.954E+09 8.443E+08 9.093E+05 5.430E+08 2.115E+06 3.044E+08
CM-244/SWT 1.507E+08 2.521E+09 1.087E+09 9.093E+05 7.001E+08 2.115E+06 3.929E+08
CM-244/AIR 2.820E+14 4.433E+15 4.174E+15 1.706E+10 1.289E+15 4.400E+14 5.451E+12
REGION 1   9.180E-12 2.960E-11 1.970E-04 4.930E-05 7.700E+03 2.000E+05 4.500E+06
           2.000E+02 5.000E+03 1.000E+04 4.000E+02 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 1.010E-09 1.510E-09 1.120E-07     3
           4.000E+02 8.000E+02 1.830E-10 2.610E-12
REGION 2   2.010E-11 3.180E-11 1.160E-03 3.240E-05 7.700E+03 2.000E+05 4.500E+06
           4.200E+01 4.000E+02 8.000E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.500E-10 5.250E-10 1.120E-07     3
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 3   2.510E-11 3.280E-11 9.000E-05 2.250E-05 7.770E+03 2.000E+05 4.500E+06
           1.400E+02 2.900E+03 5.300E+03 4.000E+02 1.250E+04 2.500E+04
           1.000E+00 1.000E+00 1.000E+00 3.860E-10 5.790E-10 1.120E-07     4
           1.600E+02 8.000E+02 1.830E-10 2.550E-12
REGION 4   2.640E-10 8.060E-11 1.300E-06 3.250E-07 7.700E+03 2.000E+05 4.500E+06
           1.500E+01 3.000E+02 6.000E+02 1.300E+03 3.000E+04 6.000E+04
           1.000E+00 1.000E+00 1.000E+00 2.660E-11 3.990E-11 1.120E-07     2
           8.000E+00 8.000E+02 1.830E-10 1.790E-12
REGION 5   2.010E-11 3.180E-11 1.160E-04 3.240E-06 7.700E+03 2.000E+05 4.500E+06
           3.200E+01 3.900E+02 7.900E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     2
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
REGION 6   2.010E-11 3.180E-11 1.160E-02 3.240E-04 7.700E+03 2.000E+05 4.500E+06
           9.200E+01 4.500E+02 8.500E+02 1.300E+03 1.000E+04 2.000E+04
           1.000E+00 1.000E+00 1.000E+00 3.030E-10 4.550E-10 1.120E-07     4
           6.400E+01 1.600E+03 1.830E-10 3.323E-12
```

SPC1 Data File

```
P-IXRESIN   11  100  100   2   1   1   0   1   1 0010    0
P-CONCLIQ   11  100  140   1   1   2   0   1   1 0110    0
P-FSLUDGE   11  100  100   1   3   1   0   1   1 0010    0
P-FCARTRG   11  100  100   2   2   1   0   0   1 0110    0
B-IXRESIN   11  100  100   2   1   1   0   1   1 0010    0
B-CONCLIQ   11  100  140   1   1   2   0   1   1 0110    0
B-FSLUDGE   11  100  100   1   3   1   0   1   1 0010    0
P-COTRASH   21  100  100   3   2   1   0   0   1 0000    0
P-NCTRASH   51  100  100   0   0   1   0   0   2 0000    0
B-COTRASH   21  100  100   3   2   1   0   0   1 0000    0
B-NCTRASH   51  100  100   0   0   1   0   0   2 0000    0
F-COTRASH   22  100  100   3   2   1   0   0   1 0000    0
F-NCTRASH   22  100  100   0   0   1   0   0   2 0000    0
I-COTRASH   23  100  100   3   2   1   0   0   1 0000    0
I+COTRASH   23  100  100   3   2   1   0   0   1 0000    0
N-SSTRASH   22  100  100   2   2   1   0   0   1 0000    0
N+SSTRASH   22  100  100   2   2   1   0   0   1 0000    0
N-LOTRASH   22  100  100   3   2   1   0   0   1 0000    0
N+LOTRASH   22  100  100   3   2   1   0   0   1 0000    0
F-PROCESS   52  100  100   0   3   1   0   1   1 0000    0
U-PROCESS   52  100  100   0   3   1   0   1   1 0000    0
I-LQSCNVL   33  100  300   3   3   1   1   0   1 0010    0
I+LQSCNVL   33  100  300   3   3   1   1   0   1 0010    0
I-ABSLIQD   33  100  300   3   3   1   1   1   1 0010    0
I+ABSLIQD   33  100  300   3   3   1   1   1   1 0010    0
I-BIOWAST   33  100  192   2   3   1   1   0   1 0010    0
I+BIOWAST   33  100  192   2   3   1   1   0   1 0010    0
N-SSWASTE   31  100  100   0   3   1   0   1   1 0000    0
N-LOWASTE   31  100  100   3   3   1   1   0   1 0000    0
L-NFRCOMP   51  100  100   0   0   1   0   0   2 0000    0
L-DECONRS   51  100  200   2   0   4   1   1   1 0310    0
N-ISOPROD   51  100  130   1   1   3   1   0   1 0210    0
N-HIGHACT   52  100  100   0   0   1   0   0   3 0000    0
N-TRITIUM   52  100  100   3   3   1   1   1   1 0000    0
N-SOURCES   52  100  100   0   0   1   0   1   2 0000    0
N-TARGETS   52  100  100   0   0   1   0   1   1 0000    0
```

SPC2 Data File

```
P-IXRESIN   11  100  165   1   1   3   0   1   1 0210    0
P-CONCLIQ   11  600  182   1   1   3   0   1   1 4210    0
P-FSLUDGE   11  100  165   1   1   3   0   1   1 0210    0
P-FCARTRG   11  100  100   1   1   3   0   1   1 0210    0
B-IXRESIN   11  100  165   1   1   3   0   1   1 0210    0
B-CONCLIQ   11  240  156   1   1   3   0   1   1 4210    0
B-FSLUDGE   11  100  165   1   1   3   0   1   1 0210    0
P-COTRASH   21  200  100   3   2   1   0   0   1 1010    0
P-NCTRASH   51  100  100   0   0   1   0   1   2 0000    0
B-COTRASH   21  200  100   3   2   1   0   0   1 1010    0
B-NCTRASH   51  100  100   0   0   1   0   1   2 0000    0
F-COTRASH   22  150  100   3   2   1   0   0   1 1010    0
F-NCTRASH   22  100  100   0   0   1   0   0   2 0000    0
I-COTRASH   23  200  100   3   2   1   0   0   1 1010    0
I+COTRASH   23  400  100   3   2   1   0   0   1 2020    0
N-SSTRASH   22  150  100   2   2   1   0   0   1 1010    0
N+SSTRASH   22  300  100   2   2   1   0   0   1 2020    0
N-LOTRASH   22  200  100   3   2   1   0   0   1 1010    0
N+LOTRASH   22  400  100   3   2   1   0   0   1 2020    0
F-PROCESS   52  100  100   0   3   1   0   1   1 0000    0
U-PROCESS   52  100  100   0   3   1   0   1   1 0000    0
I-LQSCNVL   33  128  300   3   3   1   1   1   1 1010    0
I+LQSCNVL   33  100  300   3   3   1   1   0   1 0010    0
I-ABSLIQD   33  100  165   3   3   3   0   1   1 0210    0
I+ABSLIQD   33  100  300   3   3   1   1   1   1 0010    0
I-BIOWAST   33  100  192   2   3   1   1   0   1 0010    0
I+BIOWAST   33  100  192   2   3   1   1   0   1 0010    0
N-SSWASTE   31  100  100   0   3   1   0   1   1 0000    0
N-LOWASTE   31  100  100   3   3   1   1   0   1 0000    0
L-NFRCOMP   51  100  100   0   0   1   0   1   2 0000    0
L-DECONRS   51  100  200   2   0   4   1   1   1 0310    0
N-ISOPROD   51  100  200   1   0   4   1   1   1 0310    0
N-HIGHACT   52  100  100   0   0   1   0   1   3 0000    0
N-TRITIUM   52  100  100   3   3   1   1   1   1 0000    0
N-SOURCES   52  100  100   0   0   1   0   1   2 0000    0
N-TARGETS   52  100  100   0   0   1   0   1   1 0000    0
```

SPC3 Date File

```
P-IXRESIN   11  100  200   2   0   4   0   1   1 0310    0
P-CONCLIQ   11  600  200   2   0   4   0   1   1 4310    0
P-FSLUDGE   11  100  200   1   0   4   0   1   1 0310    0
P-FCARTRG   11  100  100   2   0   4   0   1   1 0310    0
B-IXRESIN   11  100  200   2   0   4   0   1   1 0310    0
B-CONCLIQ   11  240  200   1   0   4   0   1   1 4310    0
B-FSLUDGE   11  100  200   1   0   4   0   1   1 0310    0
P-COTRASH   61 8000  200   0   0   4   0   1   1 6312    0
P-NCTRASH   51  100  100   0   0   1   0   1   2 0000    0
B-COTRASH   61 8000  200   0   0   4   0   1   1 6312    0
B-NCTRASH   51  100  100   0   0   1   0   1   2 0000    0
F-COTRASH   62 4000  200   0   0   4   0   1   1 6311    0
F-NCTRASH   22  100  100   0   0   1   0   0   2 0000    0
I-COTRASH   23 2000  200   0   0   4   0   1   1 5311    0
I+COTRASH   23 8000  200   3   0   4   0   1   1 7322    0
N-SSTRASH   22 1000  200   0   0   4   0   1   1 5311    0
N+SSTRASH   22 4000  200   2   0   4   0   1   1 7322    0
N-LOTRASH   22 2000  200   0   0   4   0   1   1 5311    0
N+LOTRASH   22 8000  200   3   0   4   0   1   1 7322    0
F-PROCESS   52  100  100   0   3   1   0   1   1 0000    0
U-PROCESS   52  100  100   0   3   1   0   1   1 0000    0
I-LQSCNVL   33  452  200   0   0   4   0   1   1 5311    0
I+LQSCNVL   33  100  300   3   3   1   1   0   1 0010    0
I-ABSLIQD   33  100  200   0   0   4   0   1   1 0310    0
I+ABSLIQD   33  100  300   3   3   1   1   1   1 0010    0
I-BIOWAST   33 1500  200   0   0   4   0   1   1 5311    0
I+BIOWAST   33  100  192   2   0   1   1   0   1 0010    0
N-SSWASTE   31  100  100   0   3   1   0   1   1 0000    0
N-LOWASTE   31  100  100   3   3   1   1   0   1 0000    0
L-NFRCOMP   51  100  100   0   0   1   0   1   2 0000    0
L-DECONRS   51 1800  200   1   0   4   0   1   1 6312    0
N-ISOPROD   51  100  200   1   0   4   1   1   1 0310    0
N-HIGHACT   52  100  100   0   0   1   0   1   3 0000    0
N-TRITIUM   52  100  100   3   3   1   1   1   1 0000    0
N-SOURCES   52  100  100   0   0   1   0   1   2 0000    0
N-TARGETS   52  100  100   0   0   1   0   1   1 0000    0
```

SPC4 Data File

```
P-IXRESIN  71 1800  200   1   0   4   0   1   1 6312   0
P-CONCLIQ  71  800  200   1   0   4   0   1   1 6312   0
P-FSLUDGE  71  500  200   1   0   4   0   1   1 6312   0
P-FCARTRG  71  100  100   2   0   4   0   1   1 0310   0
B-IXRESIN  71 1800  200   1   0   4   0   1   1 6312   0
B-CONCLIQ  71  640  200   1   0   4   0   1   1 6312   0
B-FSLUDGE  71  500  200   1   0   4   0   1   1 6312   0
P-COTRASH  71 8000  200   1   0   4   0   1   1 6312   0
P-NCTRASH  51  600  100   0   0   1   0   1   2 3010   0
B-COTRASH  71 8000  200   1   0   4   0   1   1 6312   0
B-NCTRASH  51  600  100   0   0   1   0   1   2 3010   0
F-COTRASH  72 4000  200   0   0   4   0   1   1 6311   0
F-NCTRASH  52  600  100   0   0   1   0   1   2 3020   0
I-COTRASH  63 2000  200   0   0   4   0   1   1 5311   0
I+COTRASH  73 8000  200   3   0   4   0   1   1 7322   0
N-SSTRASH  62 1000  200   0   0   4   0   1   1 5311   0
N+SSTRASH  72 4000  200   2   0   4   0   1   1 7322   0
N-LOTRASH  62 2000  200   0   0   4   0   1   1 5311   0
N+LOTRASH  72 8000  200   3   0   4   0   1   1 7322   0
F-PROCESS  52  100  100   0   3   1   0   1   1 0000   0
U-PROCESS  52  100  100   0   3   1   0   1   1 0000   0
I-LQSCNVL  63  452  200   0   0   4   0   1   1 5311   0
I+LQSCNVL  33  100  300   3   3   1   1   0   1 0010   0
I-ABSLIQD  6310000  200   0   0   4   0   1   1 5311   0
I+ABSLIQD  33  100  300   3   3   1   1   1   1 0010   0
I-BIOWAST  63 1500  200   0   0   4   0   1   1 5311   0
I+BIOWAST  73  100  192   2   0   1   1   0   1 0010   0
N-SSWASTE  31  100  100   0   3   1   0   1   1 0000   0
N-LOWASTE  31  100  100   3   3   1   1   1   1 0000   0
L-NFRCOMP  51  100  100   0   0   1   0   1   2 0000   0
L-DECONRS  71 1800  200   0   0   4   0   1   1 6312   0
N-ISOPROD  51  100  200   1   0   4   1   1   1 0310   0
N-HIGHACT  52  100  100   0   0   1   0   1   3 0000   0
N-TRITIUM  52  100  100   3   3   1   1   1   1 0000   0
N-SOURCES  52  100  100   0   0   1   0   1   2 0000   0
N-TARGETS  52  100  100   0   0   1   0   1   1 0000   0
```

NRC FORM 335
(7-77)

U.S. NUCLEAR REGULATORY COMMISSION

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Impacts Analyses Methodology Report

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7. AUTHOR(S)
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This document is prepared in three volumes and provides part of the technical support to the draft environmental impact statement (NUREG-0782) on a proposed regulation, 10CFR Part 61, setting forth licensing requirements for land disposal of low level radioactive waste. Volume 1 is a summary and analysis of the history of low level waste disposal at both commercial and government disposal facilities. Volume 2 provides a summary of low level waste volumes and characteristics as projected to the year 2000, in addition to characterizing treatment options for this waste. Volume 3 provides a methodology for analyzing the impacts of handling and disposing of low level waste based upon consideration of alternative waste forms, disposal facility design and operating practices, disposal facility environmental characteristics, and institutional control considerations.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

low-level waste
land disposal
social commitment
ground water migration
inadvertent intrusion
10 CFR Part 61
waste form
waste packaging
waste volumes
institutional controls
radioactive waste
disposal technologies
history
disposal sites

17b. IDENTIFIERS/OPEN-ENDED TERMS

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